VELOCITY AND PRESSURE EFFECTS ON PROJECTILES DUE TO VARIATION OF IGNITION PARAMETERS

Richard Otis Culver

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

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by

Richard Otis Culver, Jr.

and

Raymond Michael Burns

Thesis Advisor: J. E. Sinclair
Thesis Co-Advisor: G. A. Garrettson

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Due to Variation of Ignition Parameters

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Richard Otis Culver, Jr.
Major, United States Marine Corps
B.S., Virginia Military Institute, 1958

and

Raymond Michael Burns
Captain, United States Marine Corps
B.S., University of Southern Mississippi, 1965

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ABSTRACT

The effect of varying the point of ignition of the powder charge within a cartridge case was investigated with respect to both pressure and velocity. By installing a small tube in the base of the cartridge case it was possible to transfer the primer flash to the forward part of the case. Ignition of the powder charge at the top instead of the base gave lower chamber pressures by as much as 6,300 psi and increased muzzle velocity by 35 ft/s. When additional powder was added to obtain the same chamber pressure as a conventionally primed cartridge, muzzle velocities increased by 50 ft/s. When the pressure was brought up past the original level, but kept within normally accepted limits for the 7.62mm NATO round, velocities increased by 100 ft/s over the original load. In order to shape the pressure curve, different loading schemes were tested. Various amounts of powders and powders of different burning rates were layered within the same case, the slowest burning powder being ignited first. Lower pressures and flatter pressure peaks were realized from these configurations. The chamber pressure was reduced by 6,000 psi and the muzzle velocity increased by 100 ft/s.

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The guidance and encouragement rendered by Professor J. E. Sinclair are greatly appreciated. His enthusiasm and counseling were instrumental in bringing this project to a successful completion.

The early work done in this field during World War II by Mr. Elmer Keith of Salmon, Idaho provided us with many ideas and the background information for this project.

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I. INTRODUCTION

A. HISTORY

The history of forward priming of small arms ammunition actually extends back into the mid 1930's. Mr. Elmer Keith, Charles M. O'Neil, and Mr. Donald S. Hopkins developed a process they call "Duplex Loading" to cut down on the heating of an experimental .25 caliber rifle [2]. Mr. Keith, a well known small arms ordnance expert, reasoned that by firing the charge at the forward end of the case he could hold the powder charge in the case until it was completely consumed rather than have the powder charge burning in the barrel, and thus reduce the heating rate in the barrel.

Cartridges were assembled utilizing this technique with a primer tube. Velocities remained the same but gave about 10,000 psi less chamber pressure. Further experimentation showed that by increasing the powder charge with the forward primed cartridges, normal pressures were obtained with a definite increase in muzzle velocity.

Mr. Keith's term "Duplex Loading" did not refer to two or more different types of powders, but rather to a type of ignition system. Throughout this paper the term duplex will indicate two powder charges of progressively burning powder, and triplex will indicate three progressively burning powder charges.

Mr. Keith found that by utilizing three progressively faster burning powder charges he was able to obtain normal chamber pressures with considerably higher velocities. All such loads were compressed to prevent the powders of different burning rates from mixing within the case before firing.

During World War II Mr. Keith was sent to Frankford Arsenal for a month to work with the .50 caliber ammunition using his forward priming technique. He was able to obtain an extra 200 ft/s. Unfortunately, the pressing matters of a full scale war prevented further work on the military applications of this technique. The additional manufacturing changes necessary to install a primer tube to a cartridge already extremely effective was deemed inadvisable when maximum production was called for.

Initial inspiration for his work came from the knowledge that the power of the primer, without any powder charge, was sufficient to drive a projectile well into the bore. Mr. Keith contended that if the case were too small for the bore capacity, no velocity increase could be expected over normal loads, although chamber pressure could still be reduced. The work done on this project has proven Mr. Keith to be right in all respects.

Utilizing the classic formula; $PV = nRT$, it seemed that if the initial volume could be increased before the powder charge was completely consumed, then the pressure must decrease. This assumes that all other factors remain essentially constant for the short time period being considered. The primer tube directs the power of the primer to the base of the projectile and also prevents the powder charge from igniting until the projectile starts to move. The resulting peak pressure is not only lower but has a flatter pressure peak when compared to the pressure of a conventionally primed cartridge case.

B. IMPULSE-PROPULSION PRINCIPLES

A gun or rifle is essentially a heat engine in that its action resembles the power stroke of a gasoline engine, with the expanding hot gases driving a projectile instead of a piston. When the charge is ignited, gases are evolved from each burning grain of propellant, thus chamber pressure and heat build up rapidly. When sufficient pressure is reached the projectile begins to move against resistance from linear and rotational inertia and friction. As the projectile moves forward in the barrel, chamber volume is increased, tending to decrease the pressure. Soon after the projectile reaches the rifling the pressure is maximum. Pressure drops to about ten to thirty percent of maximum by the time the projectile reaches the muzzle, and the projectile continues to accelerate slightly beyond the muzzle. All the factors involved can be expressed in the kinetic energy theorem as follows;

$$KE = 1/2\ mv^2 = \int_0^L P(x)A\ dx - \int_0^L f(x,v)\ dx$$

where $P(x)$ is the pressure, $-f$ is the total friction force, x is the distance down the barrel, and v is the speed.

A pressure-travel curve represents pressure acting on the base of a projectile as a function of its position in the gun tube. The area under the curve represents the work done per unit area of the cross sectional area of the projectile during its travel through the gun. If the areas under two curves are equal, then the work performed per unit area is the same in each case and the muzzle velocity produced in each case will be approximately the same. To increase muzzle velocity the area under the

pressure-travel curve would have to be increased without exceeding the pressure limits of the rifle. It would seem that the ideal charge would be one that produced a pressure-travel curve which coincided with the maximum permissible pressure curve of the rifle. All guns are designed with a specific pressure-travel curve in mind, so that the desired muzzle velocity can be achieved without causing damage to the gun. A charge capable of producing such an effect would have disadvantages, however. Erosion would be increased, and excessive muzzle flash and irregular muzzle velocities would be created because of the high muzzle pressures that would exist. The actual pressure-travel curve of a rifle depends on factors such as interior ballistic variables, powder grain characteristics, and ignition characteristics.

The overall performance of a gun or rifle can be expressed in terms of its piezometric efficiency and its ballistic efficiency. Piezometric efficiency is found by dividing the mean pressure by the peak pressure, where the mean pressure is that pressure which, if uniformly exerted on the projectile over the entire length of the barrel will produce the muzzle velocity observed. The higher the piezometric efficiency the flatter the pressure-time curve. A high piezometric efficiency permits a shorter and lighter barrel to be used but requires a larger chamber. Because of high muzzle pressures, however, non-uniform muzzle velocities and greater muzzle flash may result.

Ballistic efficiency is defined as the ratio of the total work done on the projectile to the total work potential of the charge. A high ballistic efficiency is obtained by burning the charge as early as possible in the projectile's passage through the bore, in order that there

be as little residual pressure as possible. A high explosive would be ideal for ballistic efficiency but would be impractical in rifle design. By considering both ballistic efficiency and piezometric efficiency the most useful compromise may be chosen.

Interior ballistic performance is controlled by many variables including variations in ignition characteristics, rate of burning, charge weight, and chemical composition of the powder.

C. CHARACTERISTICS OF PROPELLANTS

The important properties of propellants are determined by grain composition, grain configuration, grain size, and density of loading or charge weight. A definite residual moisture content and volatility product is specified for each powder composition and granulation. The powder may also contain small percentages of stabilizer, graphite, and inert materials. Any changes in composition will affect "quickness," powders being referred to as "quick" or "slow" for a particular gun depending on their rate of burning. The pressure-travel curve for a charge of "quick" powder reaches a high peak value very early in the projectile's travel through the bore [5].

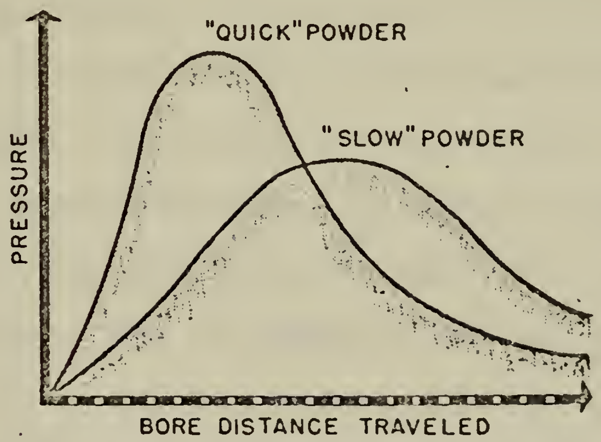


Figure 1. Characteristic pressure curves with weight of charge as a constant.

The rate of burning, or quickness, of a gunpowder varies inversely with the size of the grain. Thus, if two powders are made up of grains which are identical in composition but different in size, the powder with the smaller grains will be consumed first. If two powder charges are of equal weight, the one made up of the smaller grains will be the quicker [5].

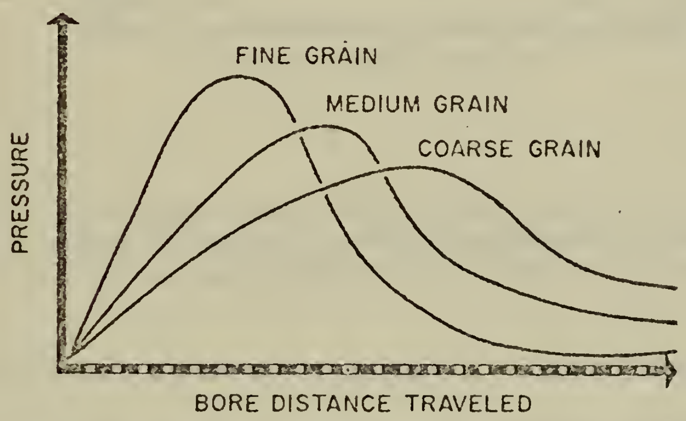


Figure 2. Pressure-travel curve illustrating the inverse relationship of grain size to quickness.

The density of packing is the ratio of the weight of the powder charge to that of the volume of water which, at standard temperature, would fill the powder chamber. It is a measure of the amount of unoccupied space in which the gases of combustion may expand before the projectile begins to move. High density of packing leaves little space for initial expansion, thus pressure builds up rapidly. Therefore, maximum pressure behind the projectile is recorded early in the projectile's travel through the gun. With low density of packing maximum pressure occurs later and is less than that achieved with high density of loading. Other factors remaining equal, increased density of packing increases maximum pressure, muzzle velocity, and muzzle loss [5].

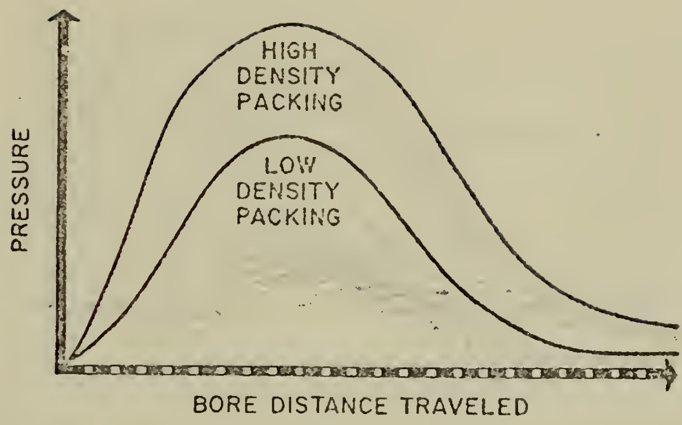


Figure 3. Pressure-travel curve illustrating the relationship of density packing to reaction pressure at a given bore distance traveled by the projectile.

Gunpowders are manufactured in grains of various shapes and sizes. Each grain of powder burns in layers parallel to the ignited surfaces. The greater the exposed surface area of a powder grain, the faster it will burn. If the area of the burning surface of the powder grains continually decreases during combustion they are termed degressive. The powder grain which maintains an approximately constant burning surface is called neutral. If the burning surface increases during combustion, the grain is considered progressive. In achieving any desired muzzle velocity, a progressive powder reaches maximum pressure much later than a degressive powder and loses pressure much more gradually. Since the work done in both cases is the same, the degressive powder produces a much larger maximum pressure. Thus, under a particular pressure limit, use of a progressive powder would produce higher muzzle velocity than would the use of a degressive powder [5].

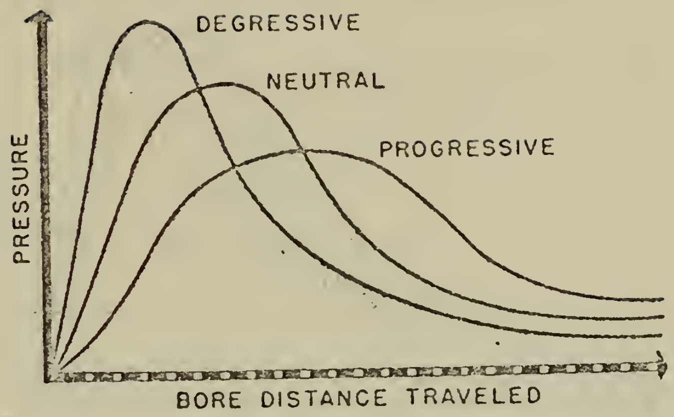


Figure 4. Characteristic pressure-travel curves for various grain configurations.

In choosing a propelling charge for a specific rifle or gun system, a compromise in composition, size, and density of packing must be made. Small arms such as hand and shoulder weapons employ quick degressive, small-grained powders in order to minimize muzzle blast even though high peak pressures result. Large guns with high-inertial projectiles and long barrels have design problems resulting from low peak pressures. They employ slow, progressive, large-grained powders.

While pressure-travel curves have been discussed up until now, a relationship must be drawn with pressure-time curves since these are the ones used in the project. The pressure-time curve shown in Figure 5 has the same peak value, but is not as steep, as the pressure-travel curve. Pressure builds up with time, but the projectile does not begin its travel down the bore until the pressure has reached an appreciable value [5].

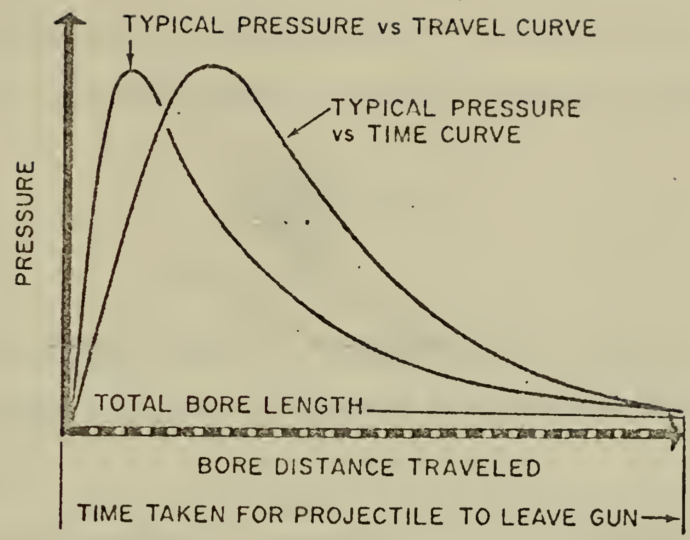


Figure 5. Typical pressure vs travel and pressure vs time curves.

D. VELOCITY-TRAVEL RELATIONSHIP

The LeDuc equation for velocity as a function of travel is based on the translation of a hyperbolic curve [5], the general equation of which is;

$v = \frac{au}{b+u}$ where v = velocity of the projectile (ft/s)

u = distance traveled in the bore (ft)

a = empirical constant (ft/s)

b = empirical constant (ft)

Muzzle velocity is given by this equation with u = length of the bore (ft). If u is allowed to approach infinity, then the muzzle velocity is equal to the limit of the general equation, as; $v = \lim_{u\to\infty} \frac{au}{b+u} = a$. Therefore, a is the theoretical value of the projectile's muzzle velocity in a gun of infinite length. The kinetic energy of the projectile when v = a is; $KE = 1/2(W/g)a^2$.

By equating a potential energy expression for the propelling gases to the kinetic energy of the projectile at $v = a$, an expression for a can be determined. From the results of calculation and experimentation:

$$a = K\left[\frac{W_c}{W_p}\right]^{1/2} D^{1/2}$$

where W_c = weight of the charge, W_p = weight of the projectile. D = density of packing, and K = a constant determined from the potential of the propellant.

The relationship between the constant b and the distance traveled u is found by differentiating the general equation $v = \frac{au}{b+u}$.

Using $v = \frac{du}{dt}$, $\frac{dv}{dt} = \frac{a\,b}{(b+u)^2}\,\frac{a\,u}{(b+u)} = \frac{a^2bu}{(b+u)^3}$, and

$$\frac{d^2v}{dt^2} = \frac{(b+u)\;a^2b - 3a^2bu}{(b+u)^4}\quad\frac{du}{dt}$$

when $\frac{d^2v}{dt^2} = 0$, $\frac{dv}{dt}$ is a maximum and $b-2u = 0$, or $u = b/2$.

Therefore, maximum acceleration (dv/dt) occurs when the bore travel u is equal to one-half of the constant b.

The propellant force acting on the projectile is given by;

$F = \frac{W_p}{g}\frac{dv}{dt}$, therefore, the pressure is $P = \frac{\frac{W_p}{g}\frac{dv}{dt}}{A}$, where A = the area of the base of the projectile.

From this equation, it is seen that the point of maximum acceleration will also be the point of maximum pressure. Therefore, the constant (b) is equal to twice the distance traveled (u) at the point of maximum pressure.

The empirical formula for b, used in all calculations by the LeDuc method is [5]; $b = B\ (1 - \frac{D}{s})\ (\frac{S}{W})^{2/3}$ where B = powder constant, S = specific gravity of the powder, s = volume of the powder chamber.

For each powder manufactured, a powder constant representing the relative quickness of the powder is determined. The value of this constant varies inversely with the velocity of burning and is therefore largest for "slow" powders. Since b is directly proportional to the powder constant, a "slow" powder will cause the point of maximum pressure to occur farther down the bore than a "fast" powder.

E. RIFLE AND PROJECTILE VARIABLES

Variations in the structure of the gun or rifle and projectile for a powder charge of fixed size and nature affect pressure and muzzle velocity. Decreasing chamber volume or increasing density of packing increases muzzle velocity and maximum pressure. The length of travel to the maximum pressure point is correspondingly decreased.

Increasing the caliber or length of the gun tube increases the muzzle velocity since energy from the expanding gases remains after the projectile leaves the weapon. Lengthening the gun tube would enable more of this energy to be coupled to the projectile, thus increasing its muzzle velocity. However, lengthening the tube increases the weight and thus decreases weapon mobility. Therefore, beyond a certain point, the added velocity is not worth the addition in weight. Also, structure problems may arise with long tubes.

Increasing projectile weight has the effect of increasing powder "quickness". The heavier the projectile, the greater the force required to move it; thus, maximum pressure is greater and is reached earlier in

the projectile's travel [5]. The increased weight will lower muzzle velocity. Since the work done in each case will be approximately the same, and work = KE = $1/2\ mv^2 = 1/2\ \frac{W}{g} v^2$, then $v = \sqrt{\frac{2(KE)g}{W}}$. That is, muzzle velocity will vary inversely with the square root of projectile weight.

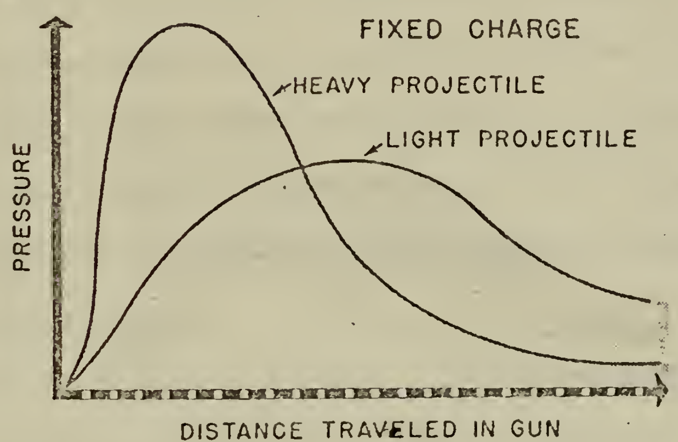


Figure 6. Characteristic pressure-travel curves for various projectile weights with fixed charge.

F. METHODS OF MEASURING PRESSURE

For many years the amount of pressure in a gun chamber was expressed in terms of "thousands of pounds per square inch" or simply psi. The means of establishing this psi figure is more relative than exact and is known as the crusher method [3]. Those outside the arms industry tended to interpret the psi figure as a specific measurement in pounds per square inch which, in fact, it is not. To eliminate the confusion that arose, a new means of expressing chamber pressure has been adopted by

the arms industry. This new terminology "Lead Units of Pressure" (abbreviated L.U.P.) and "Copper Units of Pressure" (abbreviated C.U.P.) is now in wide use. A "crusher" is sandwiched between an anvil and piston which is fitted into a hole, at right angles to and extending into the chamber. When a cartridge is fired the pressure drives the piston upwards, squeezing the "crusher" against the anvil. The crusher is then removed and its length measured by a micrometer to detect the amount of "crush" that has taken place. This measurement is then compared to a table value supplied by the crusher manufacturer. The table converts the amount of crush into a relative value of force (C.U.P. value). The crusher method does not accurately determine absolute chamber pressure which is a function of time.

Another method of measuring pressure does measure absolute chamber in psi by means of a quartz piezoelectric pressure transducer. The transducer is mounted so that it extends into the chamber and is connected to a charge gain amplifier. The amplifier is connected to an oscilloscope and the system calibrated such that the pressure can be directly read off of a picture of the trace displayed on the oscilloscope. This was the method used to take the pressure measurements in this project.

G. THEORY OF THE PRIMER TUBE

The function of the primer tube is to carry the primer ignition flash past the powder in the cartridge case to the forward or top part of the powder charge. This starts the powder burning at the front of the case and the burning direction would be from the forward part of the case toward the rear, rather than from the rear toward the front as in conventionally primed cartridges. The initial ignition of the powder, along

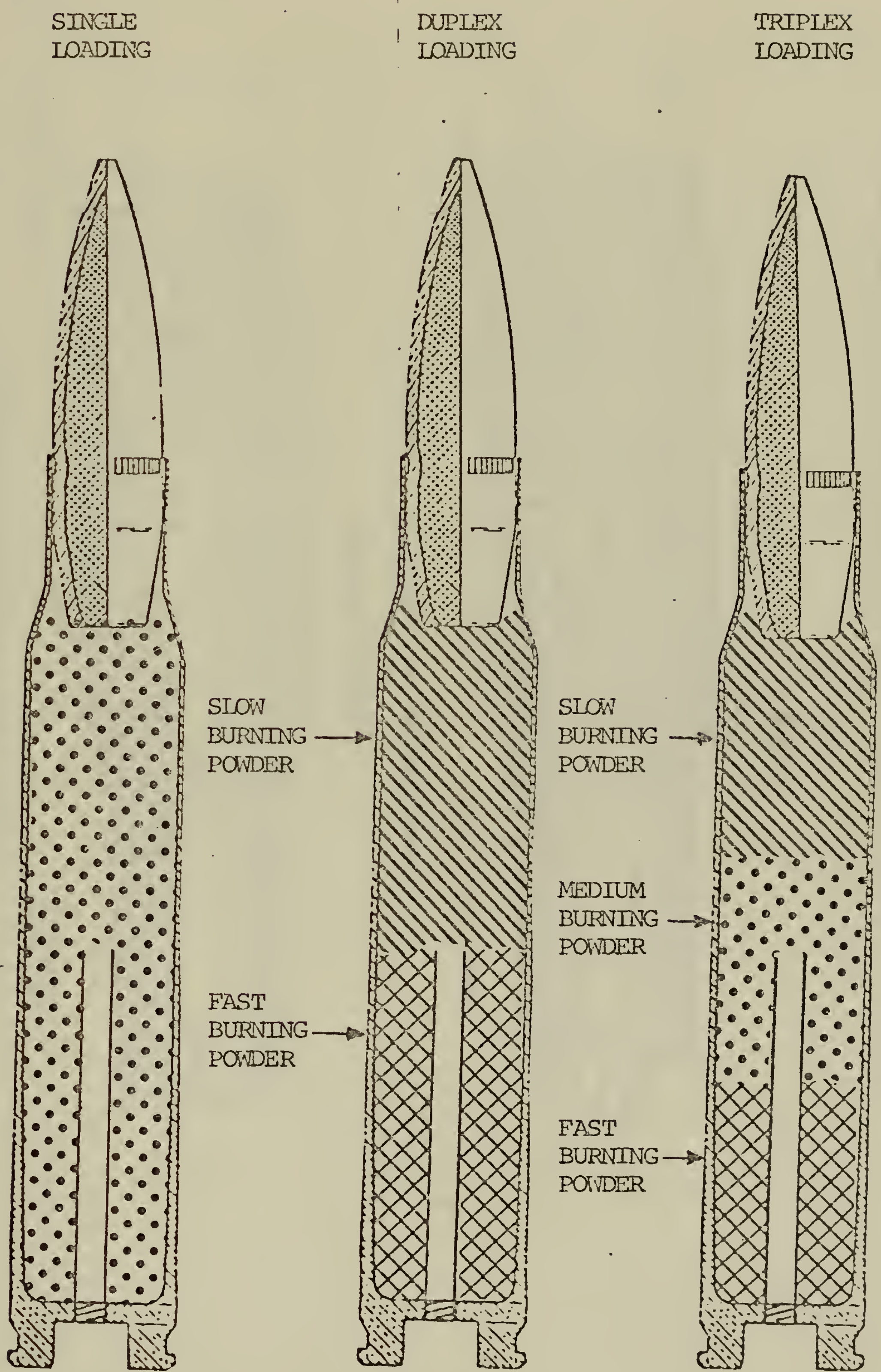
with the not inconsiderable power of the primer itself, starts the projectile into the bore long before the entire charge of the powder is burned. The projectile, having started up the bore, effectively increases the volume and thus decreases the pressure. In a conventionally primed cartridge, the powder is ignited from the base and most of it is burned before the bullet leaves the case, thus contributing to the high pressure peak associated with conventional cartridges.

H. DUPLEX AND TRIPLEX LOADS

By using duplex or triplex loads of powders with varying burning speeds, and placing the fastest burning powder at the base, the intermediate burning powder in the middle, and the slowest burning powder at the top, the slow burning powder is ignited first, driving the projectile into the bore. As the projectile proceeds down the bore, the powder charge continues to burn toward the rear with the burning rate of the powder increasing progressively as each successive powder layer is reached. As the projectile travels down the bore, the increased volume is matched with a faster burning powder, giving a much more even push and usable pressure all the way to the muzzle. A pressure-time curve plotted for such a load lacks the characteristic sharp peak of the conventional round and tends to be more even throughout its range. This effect would give less case expansion and cooler temperatures at the throat of the barrel, both of which are important in the design of automatic weapons.

An important fact of loading cartridges in this manner is that the powder charge must be sufficiently packed so that the multi-layered charge does not shift and mix the various powders. Even with the single powder charge it is necessary to have the charge reach the base of the bullet to get uniform ignition of the powder. Any shifting of the charge can cause erratic muzzle velocities and pressure curves.

Figure 7. Single, duplex, and triplex powder charges.



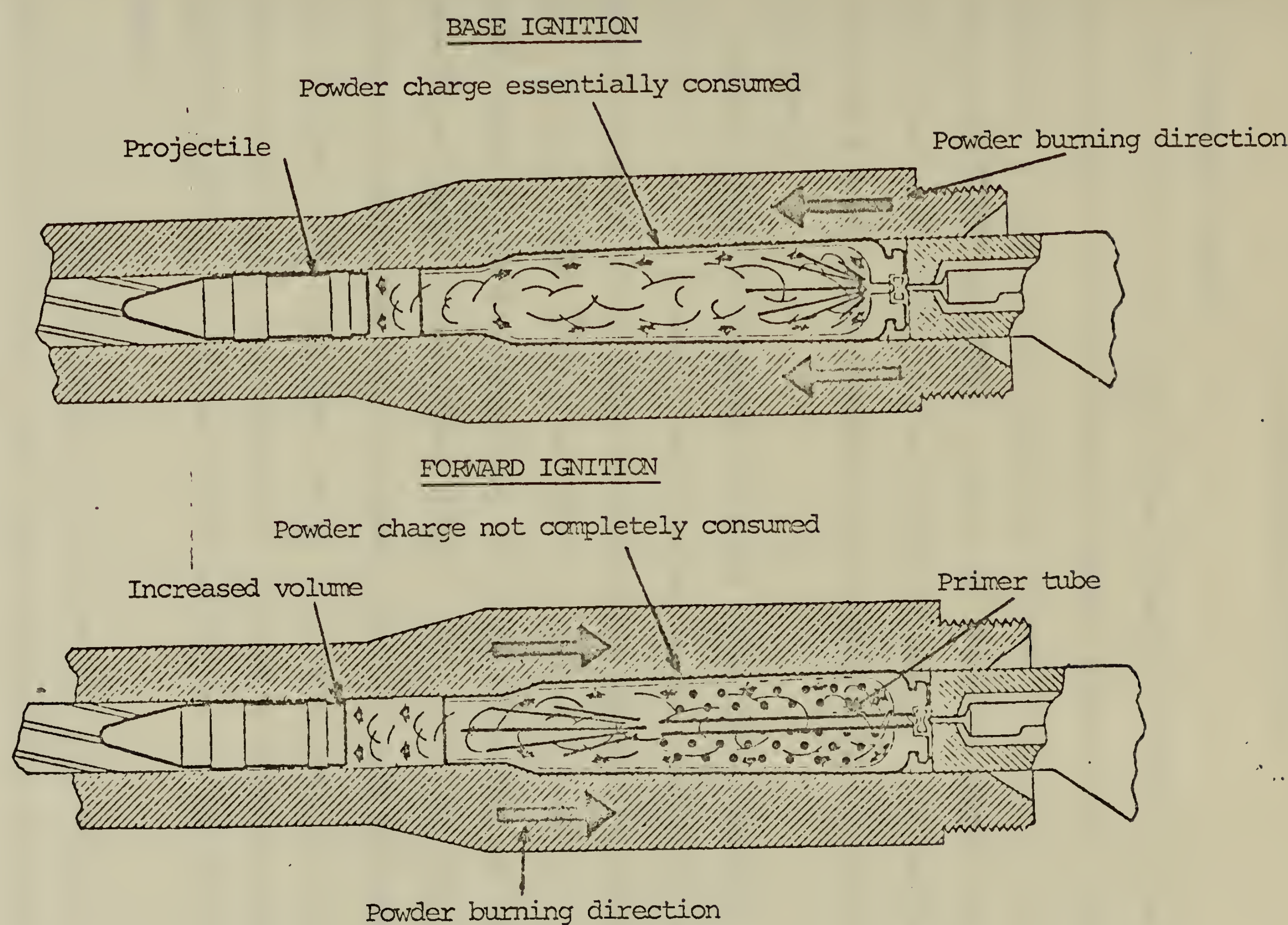


Figure 8. Forward primed vs conventionally primed cartridge case.

II. EXPERIMENTAL PROCEDURE

A. SEQUENCE OF EVENTS

While awaiting the arrival of the pressure transducer it was decided to proceed with the velocity testing portion of the project. The firing during this portion of the project was conducted using a U.S. M1904A3 rifle of Remington manufacture, with a 24" barrel of uniform twist, one turn in ten inches and having two lands and grooves. The modified forward primed cases were constructed from standard military .30-06 caliber rifle cases.

Muzzle velocity was measured by means of a digital ballistic chronograph and a set of screens placed five feet apart. The bullet passing through the first screen breaks contact and allows the chronograph to start counting. When the bullet breaks the second screen the chronograph stops counting. The time of flight of the bullet between the screens is measured and read out on a visual display using light emitting diodes. A computer program (see p.64) translates time of flight measurements into ft/s readings. The chronograph was checked for accuracy by firing a series of shots using match ammunition of known velocity as published by Frankford Arsenal, and the results were within ten ft/s of the published velocity.

Upon arrival of the transducer it was mounted in a barrel of .30-06 caliber and the system test fired. Upon extraction of the case it was found that the chamber had been reamed to the wrong size and the barrel was unsatisfactory for experimental purposes. Due to time limitations the only suitable barrel available was a 7.62mm; this was the barrel in which the transducer was ultimately mounted. Although the first portion

of the project had been conducted at an outside range it was decided to conduct both the velocity and pressure measurements in an indoor laboratory where power was available for the oscilloscope. It was discovered, however, that the chronograph would not function within the confines of the laboratory for some as yet unexplained reason. Thus, the velocity measurements had to be once again taken at the outdoor range, where the chronograph functioned properly. The independent measurements were compatible since the same barrels and loads were used in both cases. The chronograph did function for some seven rounds indoors before it became necessary to conduct the firing outdoors, and these shots were consistent with those fired at the outdoor range. Although it was desired to obtain all information on a rifle of one caliber, due to the circumstances only velocity information was obtained for the .30-06 while both velocity and pressure information was obtained for the 7.62mm.

B. CONSTRUCTION OF THE FORWARD PRIMED CARTRIDGE CASES

A detailed description of the construction of the forward primed cartridge cases was deemed necessary because of the difficulties encountered in initially making the modified cases. The construction process was one of trial and error originally and the best results were realized from the following procedures. The first sets of cases were constructed from standard military .30-06 caliber rifle cases. The cases were deprimed, primer rockets cleaned and then threaded. The initial cases were constructed with 3/32" brass tubes which were threaded with a 4-40 die and the cases were threaded with a 4-40 tap without first enlarging the flash hole in the primer pocket. The tube was held in a small vice and the die was slowly and carefully used to thread the end, backing off frequently

to insure that the threads were not crooked. The tube was then removed from the vice and tried in the case before cutting it to size. If the threads were so long as to allow the tube to protrude into the primer pocket the tube was removed from the case and filed to the proper length with a fine file. Once the tube had been properly threaded it was replaced in the vice and cut off to 1 5/8" with a razor saw. A small jeweler's screwdriver with removable blades was modified to act as a tool to install the finished primer tube. The screwdriver was disassembled and the collet-like jaws were heated to a cherry red with a small torch. The jaws were allowed to cool with quenching, leaving them soft enough to drill. The screwdriver body was then inserted in the vice and drilled to size with a 1/4" electric drill. To use this tool to insert primer tubes, the tubes were inserted in the end of the screwdriver by hand, the threaded end of the tube out. The collar of the screwdriver was then tightened down on the tube. The tool and tube were then inserted in the case and the tube screwed into the threads in the primer pocket. By continuing to turn the tool and gently withdrawing it at the same time the tube was left firmly screwed into the primer pocket.

After the initial tests it was thought that the small inside diameter of the 3/32" tube was not allowing sufficient flash to reach the powder charge to insure optimum results. For this reason a switch was made to 1/8" tubing. All procedures remained the same, except that now a 6-32 tap and die was used, and flash holes were pre-drilled in the cases with a 5/52" drill to facilitate the threading of the flash holes.

All .30-06 cases were then primed with CCI Magnum, large rifle primers and the appropriate powder charges added. Projectiles used in all configurations were standard 173 grain boat-tail match bullets as manufactured by Frankford Arsenal.

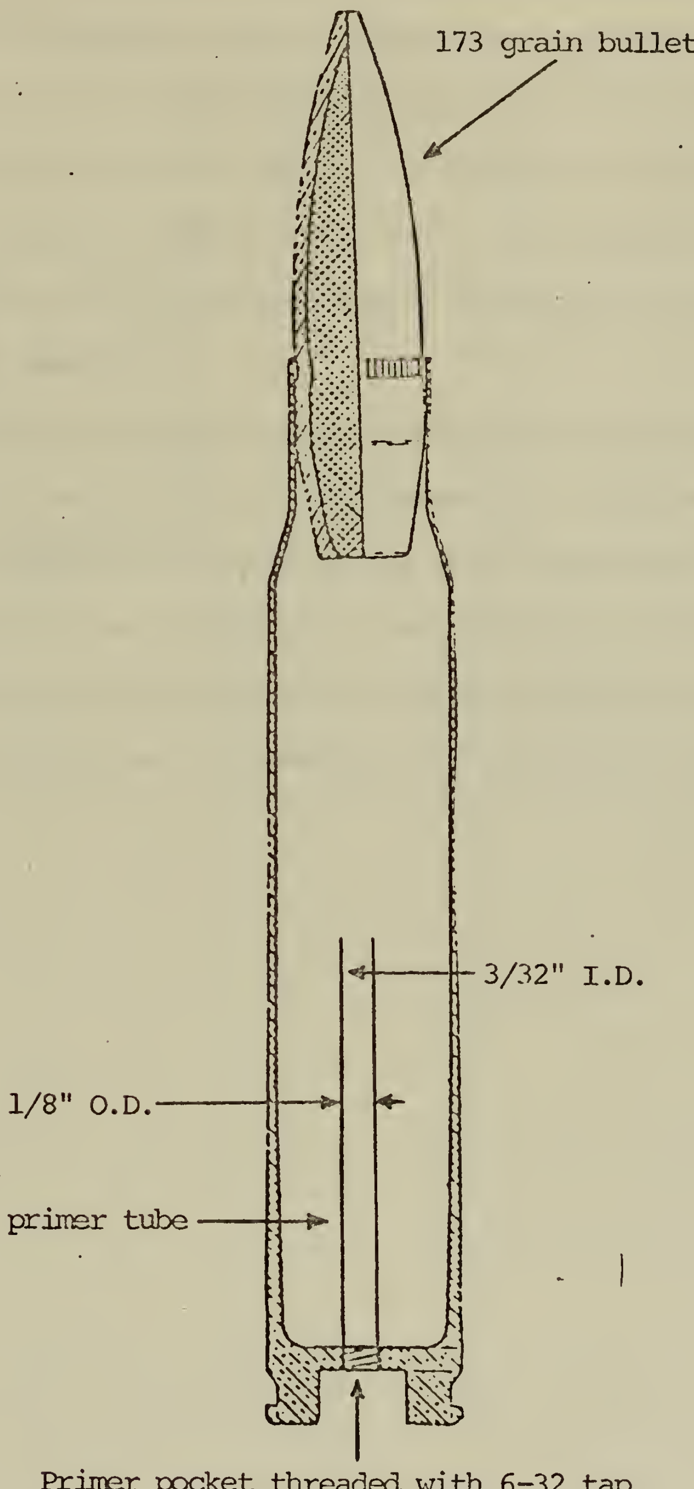
The procedures for manufacturing the forward primed 7.62mm cases remained the same with the following exception. The advice of Mr. Keith was taken to reduce the length of the primer tube to approximately half the length of the cartridge case. For the 7.62mm NATO cartridge this worked out to be .9 inches. This change was made based on the optimum results obtained when Mr. Keith was working on forward priming during World War II.

C. TYPES OF POWDERS USED

The firing done with the .30-06 was carried out using three different powders. IMR 4350, 4320, and 4064 were used in varying amounts and combinations in collecting velocity data during this portion of the testing.

The firing done with the 7.62mm was carried out using six different powders. The powders used were IMR 4350, 4320, 4227, 4064, 3031, and 4895. To gain good comparative data a lot of 7.62mm match ammunition of proven excellence and uniformity was selected. The best available lot was XM118, Lot 12015, Lake City Army Ammunition Plant. This ammunition was issued for competition at the 1964 National Matches held at Camp Perry, Ohio. The brochure issued at the National Matches by the Army Material Command specified that this ammunition contained 48 grains of IMR 4895 [4]. Upon checking the actual powder charge it was found to contain 41.5 grains of a powder that closely resembled IMR 4320. A charge of 48 grains of IMR 4895 would not fit in the cartridge case. Since the tests were comparative in nature the single powder loads were based on the powder with which the 1964 NM loads were assembled. The powder was referred to throughout the project as the 1964 NM powder.

Figure 9. Construction of the forward primed cartridge case.



Duplex and triplex loads were assembled with powders of known characteristics since no currently produced ammunition would provide a meaningful comparison. Subsequent lots of 7.62mm match ammunition available for use utilized a ball type powder which gave very erratic performance as outlined in the results of the tests. Tests were made using this powder (1968 NM) both with and without primer tube. It is believed that this was caused by the very fine-grained powder filtering into the primer tube in unpredictable amounts.

Better results with primer tube retention were obtained with the 7.62mm ammunition than with the .30-06 ammunition. Only one primer tube separation was experienced throughout the entire series of 7.62mm tests. The higher retention was attributed to the reduction in length of the tube thus reducing the effective lever arm, and the fact that more experience had been gained in assembling the cartridge by this time.

III. PRESENTATION OF DATA

A. VELOCITY DATA FOR .30-06 CALIBER RIFLE

The velocity data for this portion of the project was taken for ten different loads, each load consisting of ten rounds. The testing was conducted on two sizes of primer tubes, and control charges with no primer tubes were fired for a basis of measuring any differences in the modified cases. The following loads were fired as noted in the appropriate tables:

Table I Small Primer Tubes (3/32" Tube)

Load No.	No. of Grains	Type of Powder	Comments
1	50	IMR 4350	control charge, no tube
2	50	IMR 4350	tube installed
3	25	IMR 4350	top layer, slowest burning
	25	IMR 4064	bottom layer, fastest burning
4	17	IMR 4350	top layer, slowest burning
	17	IMR 4320	middle layer, medium burning
	17	IMR 4064	bottom layer, fastest burning

Table II Large Primer Tubes (1/8" Tube)

Load No.	No. of Grains	Type of Powder	Comments
5	50	IMR 4350	control charge, no tube
6	50	IMR 4350	tube installed
7	25	IMR 4350	top layer, slowest burning
	25	IMR 4064	bottom layer, fastest burning
8	17	IMR 4350	top layer, slowest burning
	17	IMR 4320	middle layer, medium burning
	17	IMR 4064	bottom layer, fastest burning

Table III Large Primer Tubes (1/8" Tube)

Load No.	No. of Grains	Type of Powder	Comments
9	50	IMR 4320	control charge, no tube
10	50	IMR 4320	tube installed

TABLE I

Velocity Data for .30-06 Using 3/32" Primer Tube

Load 1

msec	ft/s
2.06	2427
2.10	2381
2.08	2404
2.15	2326
2.06	2427
2.07	2415
2.10	2381
2.09	2392
2.06	2427
2.08	2404

Avg. Velocity 2398

Load 2

msec	ft/s
2.05	2439
2.10	2380
2.03	2463
2.02	2475
2.06	2427
2.04	2451
2.05	2439
2.06	2427
2.08	2402
2.04	2451

Avg. Velocity 2435

Load 3

msec	ft/s
2.07	2415
2.05	2439
2.00	2500
1.95	2564
1.97	2538
1.94	2577
2.00	2500
1.97	2538
2.01	2487
2.00	2500

Avg. Velocity 2506

Load 4

msec	ft/s
1.91	2618
1.87	2674
1.93	2590
1.95	2564
1.92	2604
2.02	2475
1.92	2604
1.93	2590
1.91	2618
1.91	2618

Avg. Velocity 2596

TABLE II

Velocity Data for .30-06 Using 1/8" Primer Tube

Load 5

msec	ft/s
2.05	2439
2.02	2475
2.04	2451
2.06	2427
2.06	2427
2.05	2439
2.08	2404
2.03	2463
2.08	2404
2.05	2439

Avg. Velocity 2437

Load 6

msec	ft/s
2.02	2475
2.06	2427
2.02	2475
2.04	2451
2.02	2475
2.01	2488
2.01	2488
2.02	2475
2.01	2488
2.02	2475

Avg. Velocity 2472

Load 7

msec	ft/s
1.94	2577
1.95	2564
1.95	2564
1.96	2551
1.94	2577
1.94	2577
1.92	2604
1.93	2590
1.94	2577
1.94	2577

Avg. Velocity 2576

Load 8

msec	ft/s
1.85	2703
1.89	2646
1.87	2674
1.89	2646
1.90	2632
1.88	2660
1.88	2660
1.89	2646
1.89	2646
1.88	2660

Avg. Velocity 2657

TABLE III

Velocity Data for .30-06 Using 1/8" Primer Tube

Load 9		Load 10	
msec	ft/s	msec	ft/s
1.91	2618	1.87	2674
1.93	2591	1.87	2674
1.89	2646	1.90	2632
1.89	2646	1.86	2688
1.87	2674	1.89	2646
1.86	2688	1.89	2646
1.91	2618	1.84	2717
1.91	2618	1.87	2674
1.89	2646	1.85	2703
1.87	2674	1.86	2688
Avg. Velocity	2642	Avg. Velocity	2674

B. VELOCITY DATA FOR 7.62mm CALIBER RIFLE

The velocity data for this portion of the project was taken for ten different loads, each load again consisting of ten rounds. Testing was conducted for only one size primer tube (1/8"), and two loads with no primer tubes were used as reference points. The following loads were fired as noted in the appropriate tables:

TABLE IV

Load No.	No. of Grains	Type of Powder	Comments
1	41.5	IMR 4895	1964 National Match, no tube
2	41.5	IMR 4895	1964 NM, tube installed
3	43.5	IMR 4895	1964 NM, tube installed
4	30.0	IMR 4350	top layer, slowest burning
	14.1	IMR 4227	bottom layer, fastest burning

TABLE V

Load No.	No. of Grains	Type of Powder	Comments
5	14.0	IMR 4350	top layer, slowest burning
	14.0	IMR 4320	middle layer, medium burning
	14.0	IMR 4064	bottom layer, fastest burning
6	16.1	IMR 4320	top layer, slowest burning
	14.8	IMR 3031	middle layer, medium burning
	9.9	IMR 4227	bottom layer, fastest burning
7	20.8	IMR 4320	top layer, slowest burning
	14.8	IMR 3031	middle layer, medium burning
	6.9	IMR 4227	bottom layer, fastest burning
8	14.0	IMR 4350	top layer, slowest burning
	14.0	IMR 4064	middle layer, medium burning
	14.0	IMR 3031	bottom layer, fastest burning

TABLE VI

Load No.	No. of Grains	Type of Powder	Comments
9	44.5	IMR 4895	1964 NM, without tube
10	44.5	IMR 4895	1964 NM, tube installed

TABLE IV

Velocity Data for 7.62mm Using 1/8" Primer Tube

Load 1

msec	ft/s
1.90	2632
1.90	2632
1.90	2632
1.91	2618
1.95	2564
1.95	2564
1.95	2564
1.93	2591
1.91	2618
1.92	2604

Avg. Velocity 2602

Load 2

msec	ft/s
1.96	2551
1.96	2551
1.98	2525
1.96	2551
1.98	2525
1.97	2538
2.01	2487
1.97	2538
1.98	2525
1.96	2551

Avg. Velocity 2534

Load 3

msec	ft/s
1.89	2646
1.88	2660
1.88	2660
1.88	2660
1.90	2632
1.87	2674
1.88	2660
1.91	2618
1.87	2674
1.88	2660

Avg. Velocity 2654

Load 4

msec	ft/s
1.89	2646
1.91	2618
1.92	2604
1.92	2604
1.90	2632
1.89	2646
1.91	2618
1.88	2660
1.90	2632
1.89	2646

Avg. Velocity 2631

TABLE V

Velocity Data for 7.62mm Using 1/8" Primer Tube

Load 5

msec	ft/s
2.15	2336
2.12	2358
2.12	2358
2.12	2358
2.16	2314
2.14	2336
2.12	2358
2.16	2314
2.15	2336
2.13	2347
Avg. Velocity	2342

Load 6

msec	ft/s
1.93	2591
1.92	2604
1.92	2604
1.91	2618
1.94	2577
1.92	2604
1.93	2591
1.90	2632
1.92	2604
1.94	2577
Avg. Velocity	2600

Load 7

msec	ft/s
1.92	2604
1.89	2646
1.90	2632
1.91	2618
1.87	2674
1.91	2618
1.90	2632
1.92	2604
1.89	2646
1.92	2604
Avg. Velocity	2628

Load 8

msec	ft/s
1.86	2688
1.84	2717
1.87	2673
1.87	2673
1.85	2703
1.84	2717
1.88	2660
1.86	2688
1.85	2703
1.86	2688
Avg. Velocity	2691

TABLE VI

Velocity Data for 7.62mm Using 1/8" Primer Tube

Load 9 msec	Load 9 ft/s	Load 10 msec	Load 10 ft/s
1.86	2688	1.85	2703
1.85	2703	1.85	2703
1.86	2688	1.87	2674
1.83	2732	1.86	2688
1.88	2660	1.87	2674
1.85	2703	1.87	2674
1.87	2674	1.85	2703
1.85	2703	1.82	2747
1.86	2688	1.83	2732
1.84	2717	1.86	2688
Avg. Velocity	2696	Avg. Velocity	2699

C. PRESSURE DATA FOR 7.62mm CALIBER RIFLE

Pressure data was obtained for match ammunition both with and without the primer tube in place, and for a single duplex load and five triplex loads of various charge configurations. A minimum of five time-pressure curves were taken for each load.

The oscilloscope was set for two volts/cm or 10,000 psi/cm and the base line or zero pressure line for all shots was as indicated in Figure 11. The time or horizontal axis on the oscilloscope was set for .1 msec/cm. Since time of flight in the barrel is approximately .001 second (Figure 10) the bullet exited the barrel at the right edge of the photographs with relatively low pressures.

1. <u>1964 Match Ammunition With and Without Primer Tube</u>

This powder load was reported to contain 48 grains of IMR 4895, producing a chamber pressure of 44,000 psi [4]. When examined the load was found to contain 41.5 grains of powder. The average peak pressure obtained for this load was 40,000 psi (Figure 12).

The same powder charge with primer tube installed averaged 33,700 psi (Figure 13).

An extra grain of powder was added to the conventional case for a total of 42.5 grains. The average peak pressure for this load was 41,000 psi (Figure 14).

The same load of 42.5 grains with primer tube installed averaged 36,000 psi (Figure 15). No velocity data was obtained for this particular load.

The load was increased another grain to 43.5 grains, and with primer tube installed the average peak pressure obtained was 42,000 psi (Figure 16).

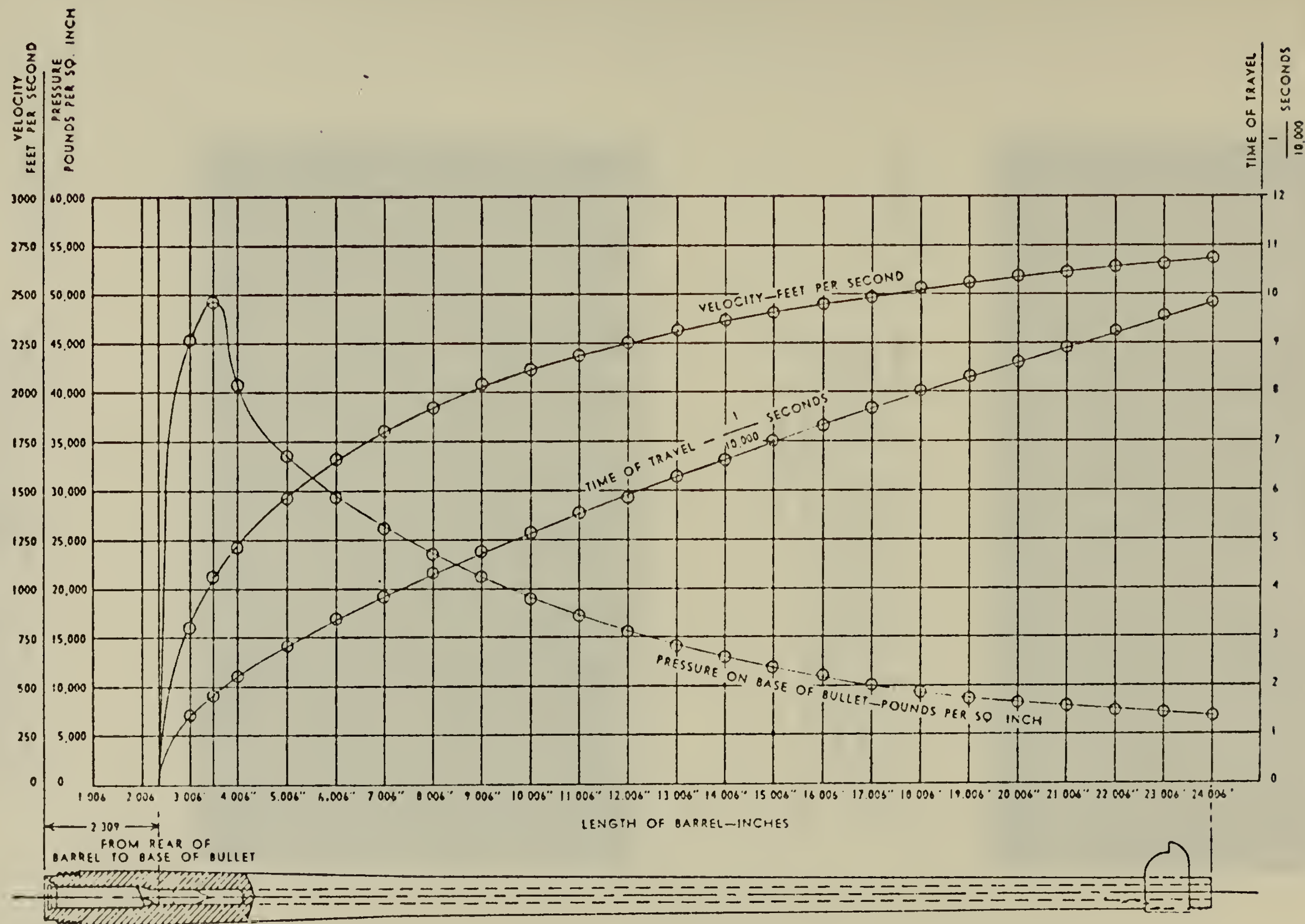


Figure 10. Composite graph of time of travel, velocity, and pressure vs barrel length.

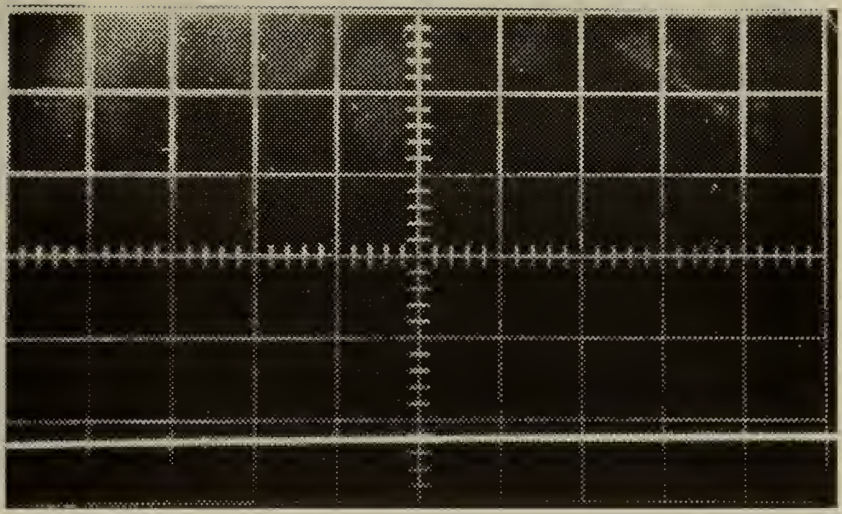


Figure 11. Base line setting for all pressure readings. Vertical axis (pressure) scale setting at 10,000 psi/cm. Horizontal axis (time) scale setting at .1 msec/cm.

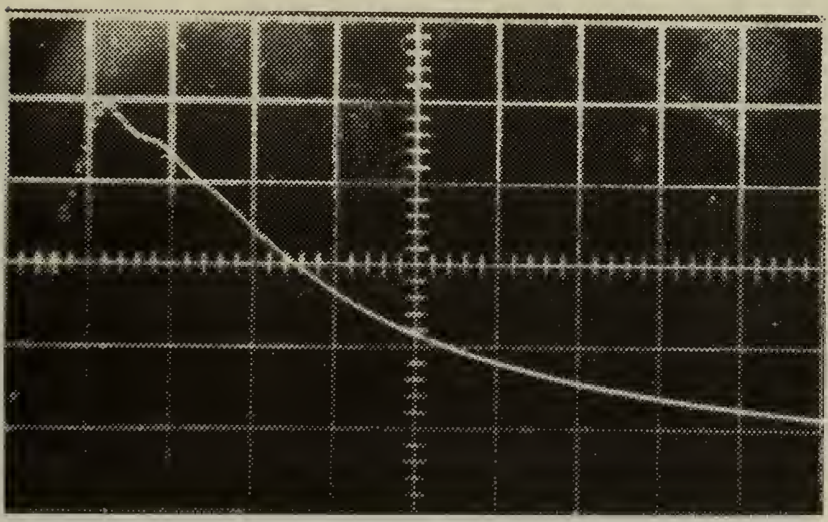
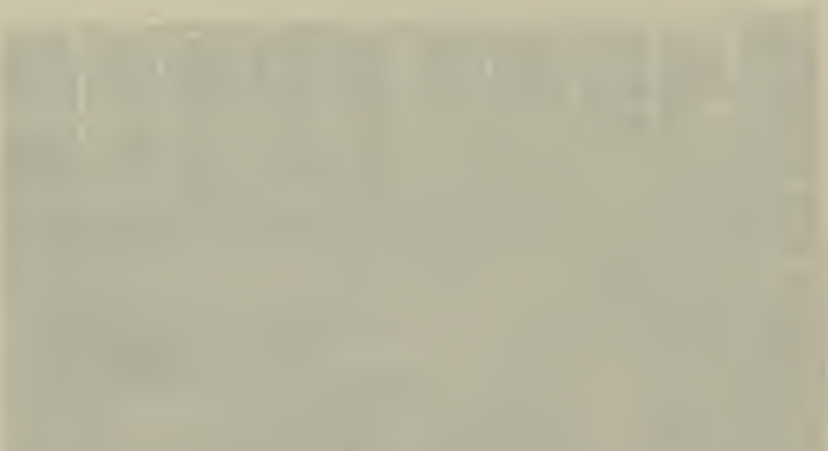


Figure 12. Load No. 1, Table IV, 41.5 grains of 1964 NM powder. Average peak chamber pressure 40,000 psi.



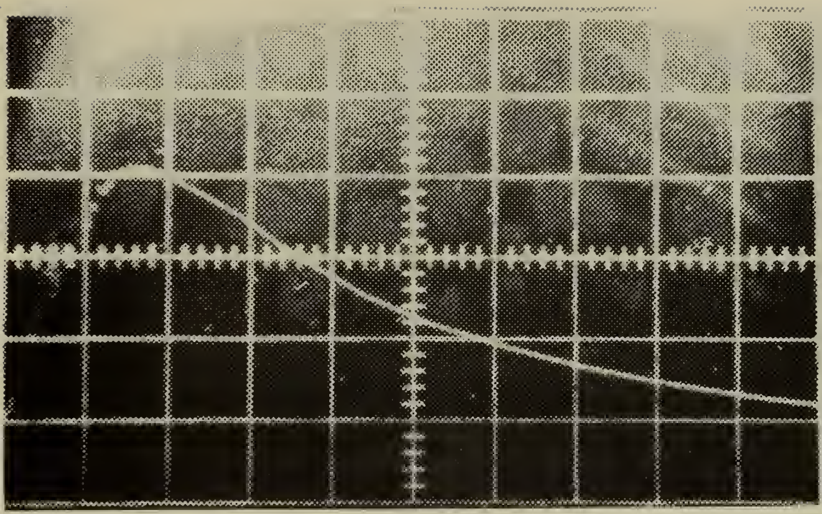


Figure 13. Load No. 2, Table IV, 41.5 grains of 1964 NM powder with primer tube installed. Average peak chamber pressure 33,700 psi.

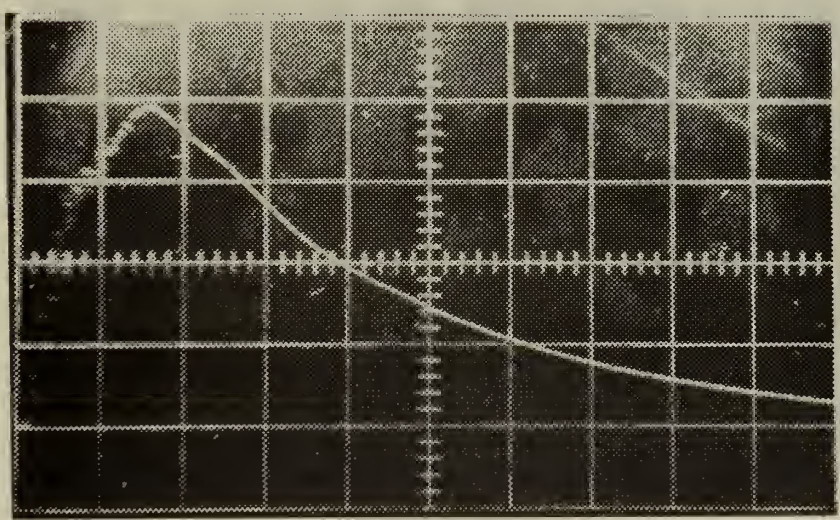


Figure 14. 42.5 grains of 1964 NM powder, without primer tube installed. Average peak chamber pressure 41,000 psi.

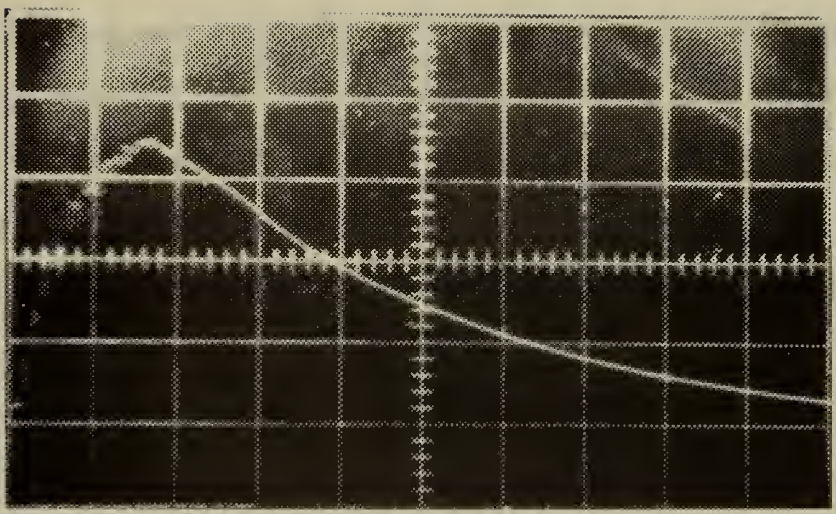


Figure 15. 42.5 grains of 1964 NM powder, with primer tube installed. Average peak chamber pressure 36,000 psi.

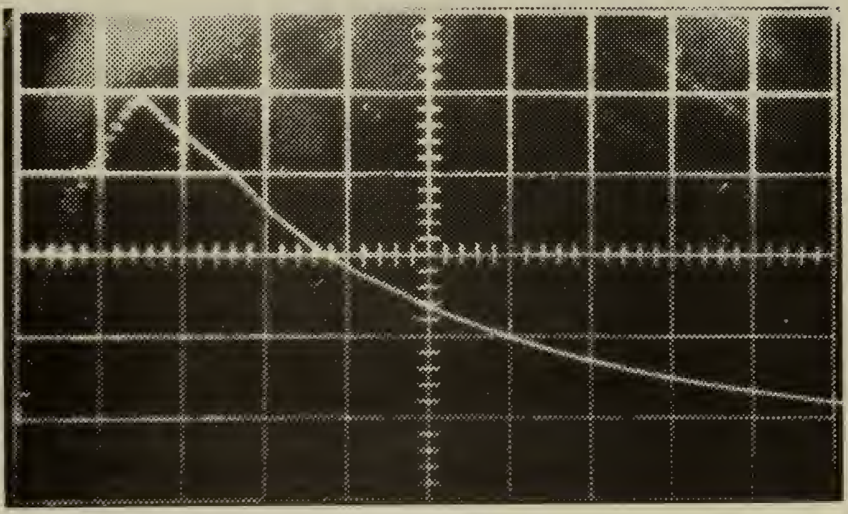
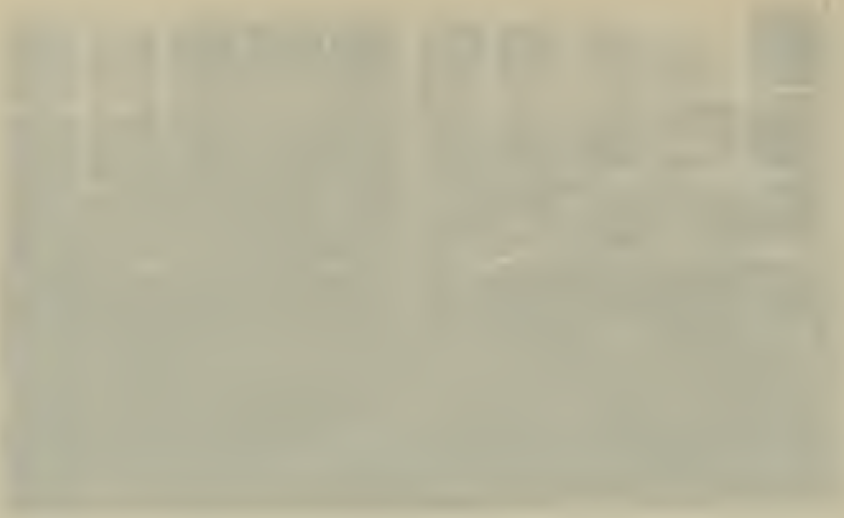


Figure 16. Load No. 3, Table IV, 43.5 grains of 1964 NM powder with primer tube installed. Average peak chamber pressure 42,000 psi.



The load was increased to 44.5 grains with primer tube installed and the average peak pressure obtained was 47,700 psi (Figure 17). The same load without tube exceeded 50,000 psi on all shots (Figure 18). The exact pressure was undetermined since it peaked off-scope due to the two volts/cm setting and the ten volt limitation of the amplifier.

2. <u>1968 Match Ammunition With and Without Primer Tube</u>

No data was available to determine what type of powder was used in the 1968 match ammunition other than the fact that it was ball type powder. The same load was used in shots with and without the tube inserted in the case. Without the tube the average peak pressure obtained was 39,500 psi (Figure 19) and the readings were very consistent.

With the tube inserted the average peak pressure obtained was 34,300 psi (Figure 20). Although the pressure averaged 5,000 psi lower, the data obtained was very inconsistent, ranging from 28,000-42,000 psi. This may be explained by fine grains of powder dropping into the primer tube prior to firing.

3. <u>Duplex Load With Primer Tube</u>

Only one duplex load was tested and it consisted of 30.0 grains of IMR 4350 as the slower burning top layer, and 14.1 grains of IMR 4227 as the faster burning bottom layer. This load was by far the most consistent load tested, every shot having a maximum peak pressure of 48,000 psi (Figure 21).

4. <u>Triplex Loads With Primer Tube</u>

Five triplex loads were tested using various powder types and loads. Triplex Load No. 5, Table V, consisted of 14 grains each of IMR 4350, 4320, and 4064. These powders were layered from top to bottom

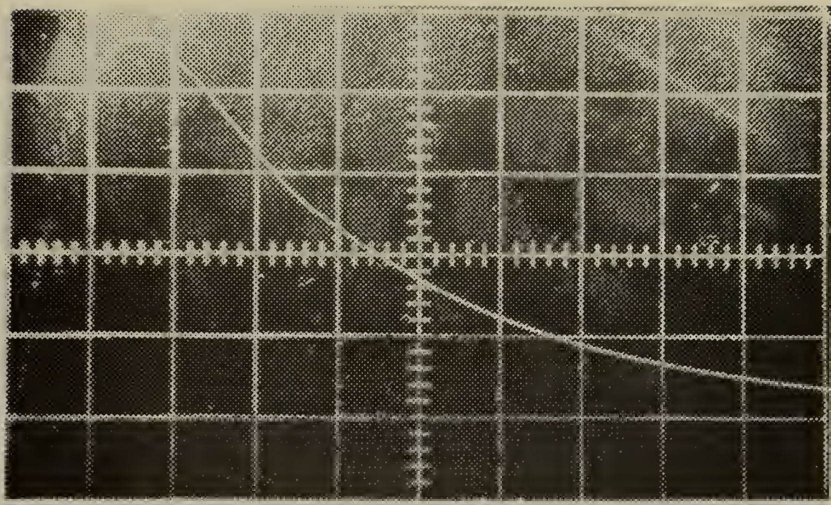


Figure 17. Load No. 10, Table VI, 44.5 grains of 1964 NM powder with primer tube installed. Average peak chamber pressure 47,700 psi.

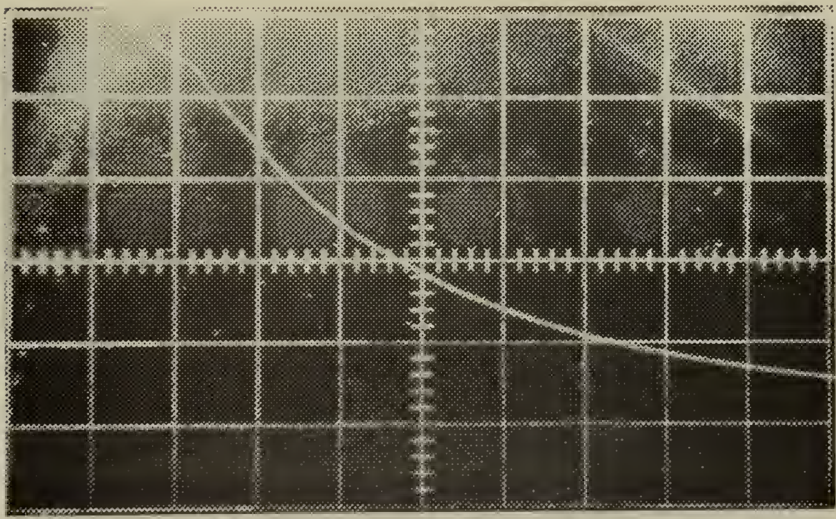
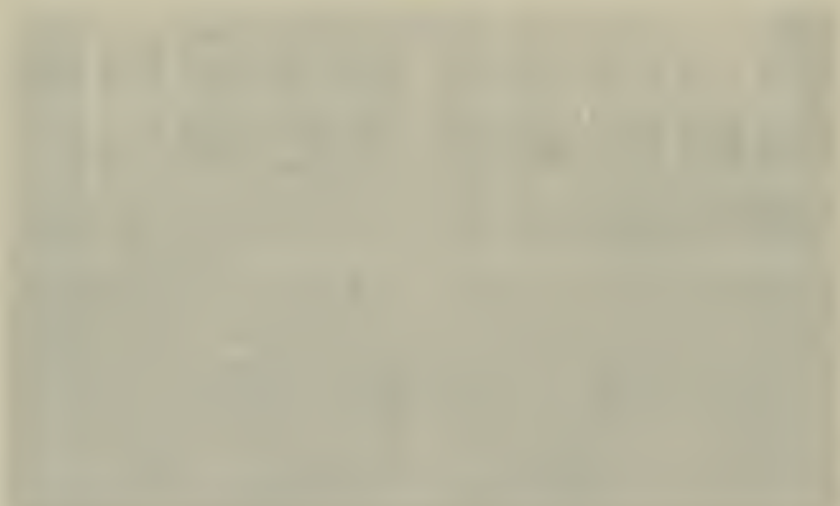


Figure 18. Load No. 9, Table VI, 44.5 grains of 1964 NM powder without primer tube installed. Average peak chamber pressure exceeds 50,000 psi.



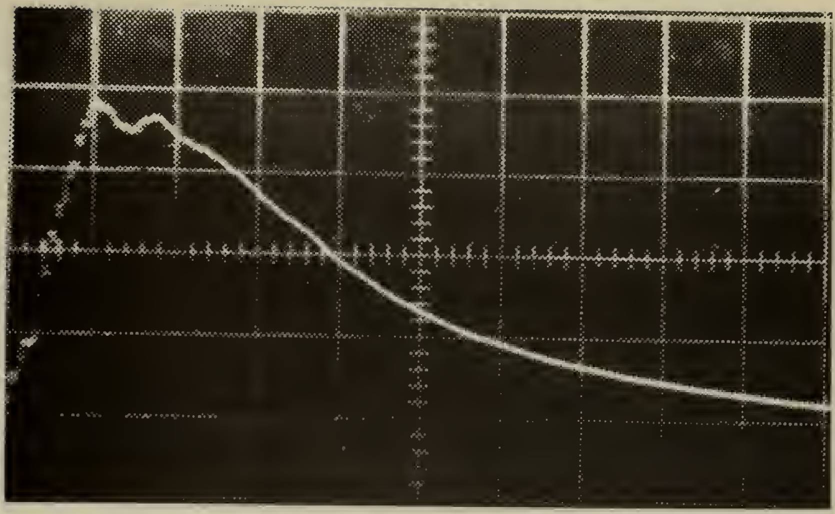


Figure 19. 1968 NM powder without primer tube installed. Average peak chamber pressure 39,500 psi.

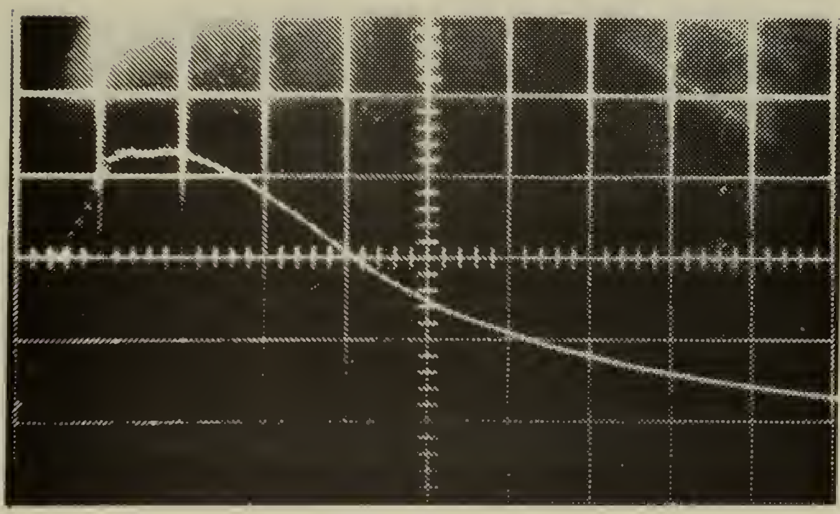


Figure 20. 1968 NM powder with primer tube installed. Average peak chamber pressure 34,300 psi.

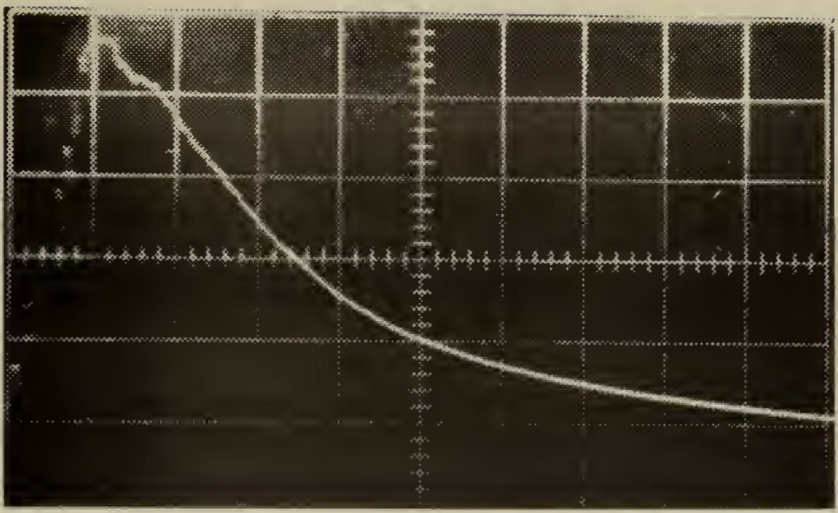


Figure 21. Load No. 4, Table IV, Duplex load with primer tube installed. Average peak chamber pressure 48,000 psi.

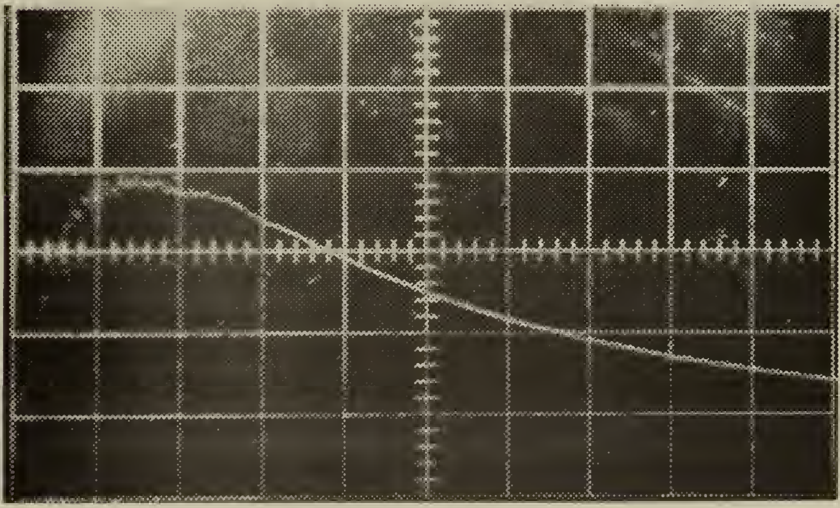


Figure 22. Load No. 5, Table V. Triplex load with primer tube installed. Average peak chamber pressure 30,500 psi.

in order of increasing "quickness," the IMR 4350 was the "slowest" and the IMR 4064 the "quickest" of the three powders. This load gave an average peak pressure of 30,500 psi (Figure 22).

Triplex Load No. 6, Table V, was made up of 16.1 grains of IMR 4320, 14.8 grains of IMR 3031, and 9.9 grains of IMR 4227 in increasing "quickness" from top to bottom. This load of 40.8 grains gave an average peak pressure of 42,000 psi (Figure 23).

Triplex Load No. 7, Table V, was made up of 20.8 grains of IMR 4320, 14.4 grains of IMR 3031, and 6.9 grains of IMR 4227 for a total load of 42.5 grains. This load gave an average peak pressure of 42,500 psi (Figure 24).

Triplex Load No. 8, Table V, consisted of 14 grains each of IMR 4350, 4064, and 3031. This load of 42 grains gave an average peak pressure of 34,000 psi (Figure 25).

The last triplex load consisted of 20.8 grains of IMR 4320, 14.8 grains of IMR 3031, and 9.9 grains of IMR 4227, for a total load of 45.5 grains. This particular load exhibited all the classical signs of excessive pressure including loose primer and difficult extraction. The pressure exceeded 50,000 psi and it was decided to not test this load any further (Figure 26).

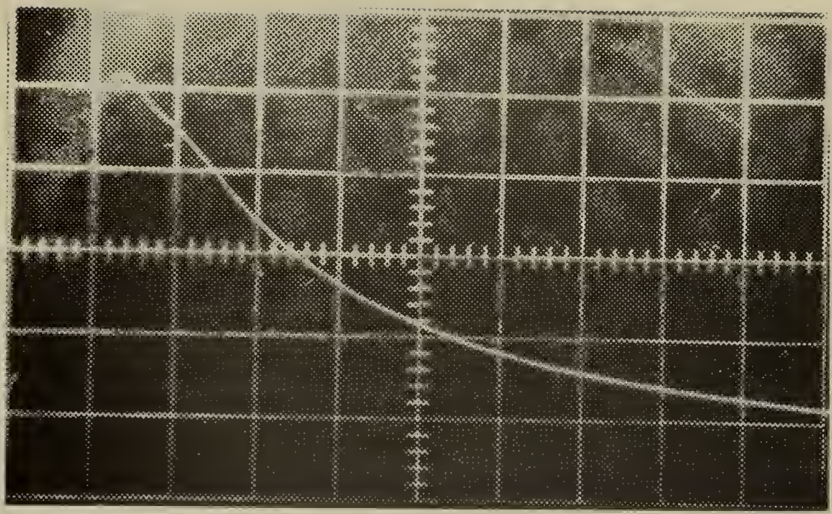


Figure 23. Load No. 6, Table V. Triplex load with primer tube installed. Average peak chamber pressure 42,000 psi.

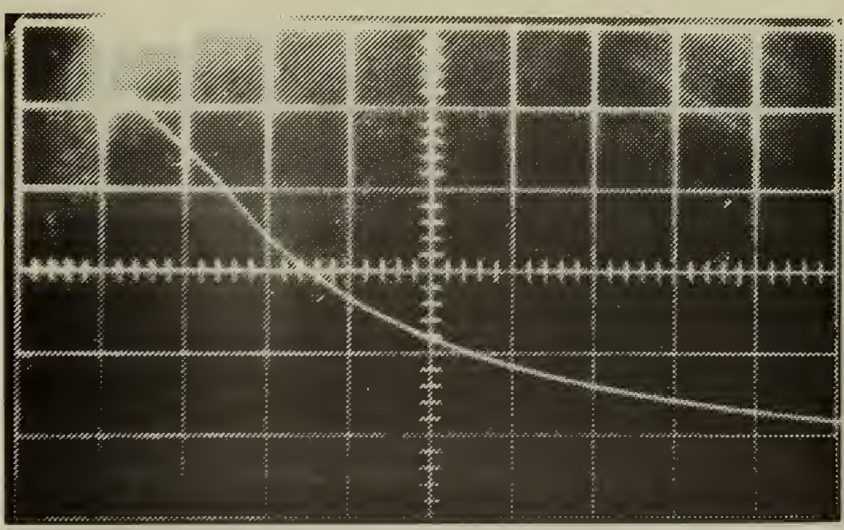
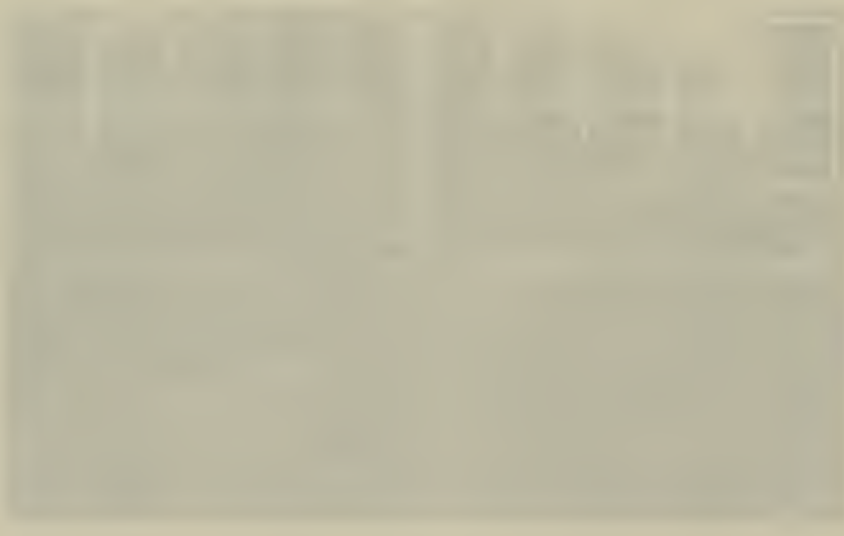


Figure 24. Load No. 7, Table V. Triplex load with primer tube installed. Average peak chamber pressure 42,500 psi.



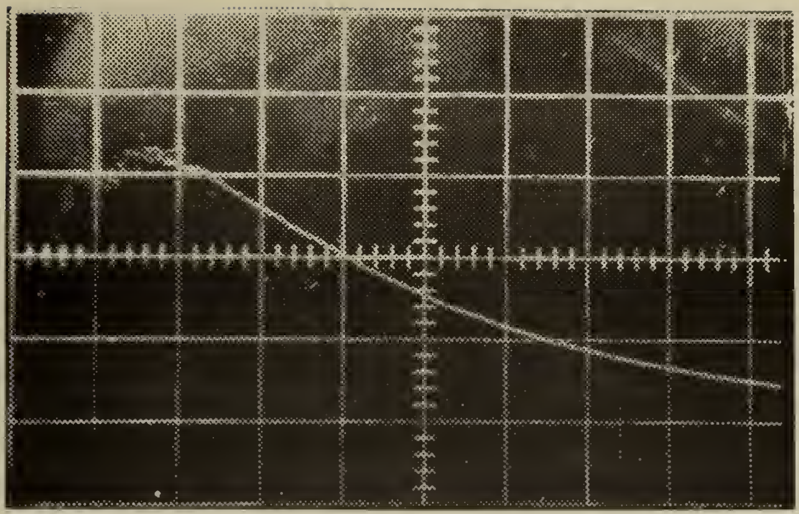


Figure 25. Load No. 8, Table V. Triplex load with primer tube installed. Average peak chamber pressure 34,000 psi.

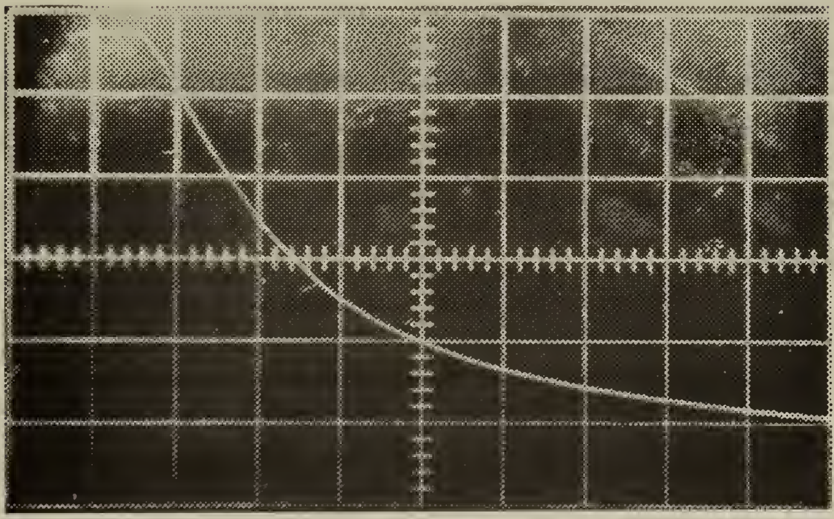
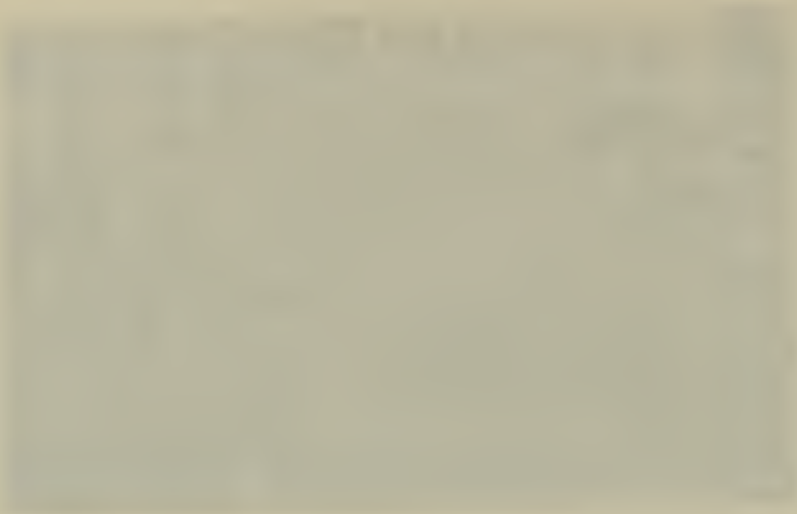
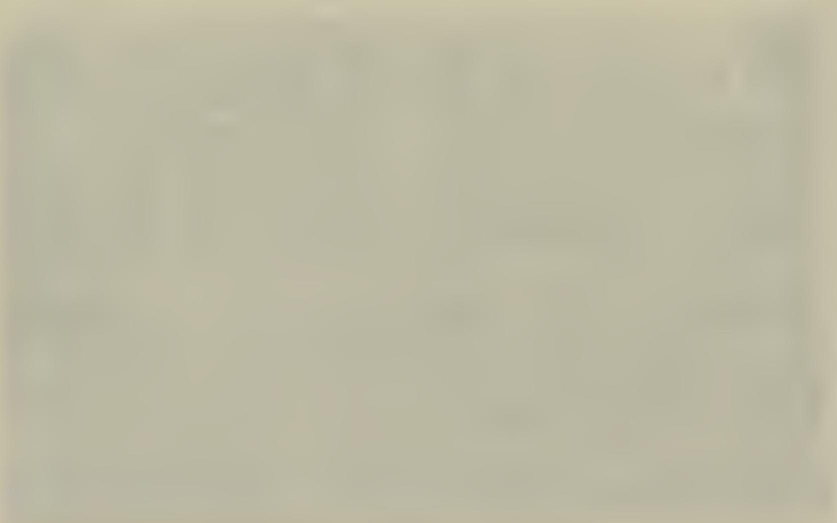


Figure 26. 45.5 grains. Triplex load with primer tube installed. Pressures in excess of 50,000 psi resulted in loose primer and extraction difficulty.





IV. CONCLUSIONS

A. FINDINGS

1. Powder Charges with Single Type of Powder

When using a single type of powder of a given grain weight, significantly lower pressures were obtained with the forward priming technique, than when conventional priming techniques were used. Velocities for the same weight of powder were essentially the same for either priming technique.

The above fact allowed the practice of adding small carefully weighed amounts of additional powder to the forward primed cartridges to bring the pressure curve back to a normal level. When the pressure of both cartridges was again equal, the forward primed cartridge gave the highest velocity. The same amount of carefully weighed powder could be added to the conventional cartridge, however the attendant increase in pressure appeared to be excessive. When more powder was added to the forward primed cartridge and the pressure gradually brought up past its original level, but kept within normally accepted pressure limits (48,000-50,000 psi) for the 7.62mm NATO round, velocities increased to approximately 2700 ft/s, a gain of 100 ft/s over the original load. The same amount of additional powder was added to the conventional cartridge. This resulted in the same velocity gain as the forward primed round, but the pressure exceeded the scale limitation of the grid and the charge amplifier, in this case, 50,000 psi.

The above results were obtained using a tubular grained IMR powder. The same experiment was performed using the ball powder currently being used in 7.62mm Match Ammunition, giving erratic results. Some very low

pressure readings were obtained, but some approached the same level as the cartridge without the primer tube. Efforts were then made to load the cartridges as carefully as possible by leaving the primer tubes plugged until the powder charge was properly in place. This practice gave the same erratic results as the first batch of ball powder cartridges. The erratic pressure results were felt to be the result of an unpredictable amount of the tiny grains of ball powder filtering down into the primer tube. Further experimentation with ball type powders was dropped due to time limitations, however, it is possible that some excellent results might be obtained by using a combustible cover (such as cellophane) over the end of the primer tube, as some of the lowest pressure readings were obtained with the ball type powder.

2. Multiplex Powder Charges

When relatively slow burning powders of the type normally associated with the loading of large bore rifles were used (i.e., IMR 4350, IMR 4320, IMR 4064, and IMR 3031) in proportional amounts and arranged in order of burning speed (slowest burning ignited first) no problems were encountered and greatly reduced pressures were achieved.

With the .30-06, duplex and triplex charges increased muzzle velocities a significant amount. Since no pressure instrumentation was available for the .30-06, unfortunately no pressure data is available.

The 7.62mm achieved much lower pressures, but only at the expense of reduced velocities. No additional powder could be added using the powders mentioned in paragraph 1 above, because the maximum case volume had been exceeded.

Switching to faster burning powders for duplex and triplex loads resulted in higher velocities, but the advantage of low pressure peaks was lost. One such triplex loading in the 7.62mm exhibited all the classic signs of pressure including loosened primer, gas leakage around the primer, bright ejector mark on the base of the cartridge, expanded case head and difficult extraction. Further experimentation was dropped along these lines in the interest of safety and practicality.

B. OPINIONS

1. Reduction of Pressure with Primer Tube

The reduction of pressure utilizing forward priming techniques is believed to be due to several factors. The energy of the primer alone is usually sufficient to propel the projectile a short distance into the bore. The addition of the primer tube accomplishes two things. First it directs the energy of the primer at the base of the projectile, and second it serves to ignite the very forward end of the powder charge. This causes the projectile to be propelled into the bore prior to the complete combustion of the powder charge. This increases the effective volume of the combustion chamber. If the classic formula $PV = nRT$ is taken to be a valid approximation here, an instantaneous evaluation of the results of increasing the volume, with all other variables considered to be essentially constant at that particular instant, would of necessity require that the pressure be reduced.

Once the projectile starts to move, the relative volume increases rapidly, thus further decreasing the pressure before the powder charge is completely consumed.

Even though the primer tube does occupy some of the internal volume of the case, a condition that should raise the initial pressures, the distance the projectile is moved down the bore prior to the combustion of the powder charge more than compensates for the small decrease in volume of the cartridge case due to the primer tube.

The reduction of pressure should also have the added beneficial effect of lower bore temperatures. A reduction in bore temperature would be very beneficial in cutting down on bore erosion, especially in weapons with a high cyclic rate of fire.

2. Multiplex Powder Charges

Theoretically it should be possible to adjust the powder charge burning rate so that it would become progressively faster as the projectile proceeds down the bore, thus allowing a lower pressure peak of longer duration giving the bullet a constant push all the way down the bore. The fact that higher velocities were obtained with the .30-06 and not with the 7.62mm when utilizing the same powders in similar proportions (although not in the same amounts, due to the smaller case capacity of the 7.62mm) suggests the possibility that there is an optimum case volume for a given bore size. The long flat pressure curve obtained with the 7.62mm (see figure 22) shows excellent promise, but the fact that the case was filled to absolute capacity precluded the addition of enough powder to take advantage of pressure reduction in the pursuit of high velocities. A cartridge the size of the .300 Winchester should provide an ideal vehicle to prove the theory.

A word of caution is due here. When using charges of several different burning rates, the charge must be sufficiently compressed to prevent the charges from shifting or mixing. The second note is one of

technique. Often compressed powder charges are mentioned that just do not seem to want to fit in the case. Generally such charges are dropped into the case through a long tube, and then the case is gently tapped on the side near the base to cause the powder to settle. When triplex charges are put in it is sometimes necessary to go through this procedure for each layer of powder.

The multiplex charge idea deserves further investigation, however time and the lack of a rifle of sufficient case capacity adapted to pressure instrumentation prevented extensive research into this aspect of forward ignition. The multiplex idea would seem to be ideally suited to large caliber naval guns, field artillery, and tank guns. Such guns already utilize a perforated primer tube and it should pose no great problem to use a solid primer tube filled with black powder or some similar highly combustible material to insure uniform positive ignition. Charges of different burning rates could be identified by different colored powder bags, or the bags could be numbered in loading sequence.

3. Production Techniques and Refinements

In reality the process of manufacturing small arms ammunition with primer tubes could be easily solved. A slightly deepened primer pocket would allow the use of a tube with a primer pocket sized flange to be pressed into the case from the rear. This would allow for rapid production and avoid any case or tube threading problems. The tube could be of thinner gauge metal to cut down on both internal case volume reduction and total case weight.

A further refinement would be the construction of the primer tube out of a combustible plastic such as cellulose nitrate, treated so that it would resist ignition by the primer, but would ignite at the combustion

temperature of the powder charge. This technique would allow higher velocities from cases such as the 7.62mm NATO cartridge that have limited case capacity, since the tube occupies internal case volume that would house several additional grains of powder.

4. Possible Applications

As suggested above, the system is adaptable to both small arms and large bore weapons including tank guns, aircraft cannon, artillery, and naval guns. In field artillery current ballistics could be maintained with a great savings in weight and portability due to the low pressures involved. The mounting system and barrels on aircraft cannon, naval guns, and tanks could be lighter, with an attendant weight savings for the entire vehicle.

For a given set of ballistics, bore erosion would be less, since pressure and thus bore temperatures would be less. This would allow higher rates of fire, or with normal rates of fire, longer time periods would be possible before it became necessary to reline bores or replace barrels.

Flat trajectory weapons such as tank guns could be given higher velocity, extending their effective range and cutting down on range estimation error.

C. RECOMMENDATIONS

It is recommended that further research be conducted with forward priming techniques to include work with duplex and triplex charges with a cartridge of sufficient case capacity to take advantage of progressive burning rates of properly arranged powder charges. As mentioned before, the .300 Winchester should provide sufficient case capacity for a meaningful research project.

It is further recommended that the research be expanded to include 105mm artillery pieces, five inch naval guns, and 20mm aircraft cannon.

APPENDIX A

List of Equipment Used

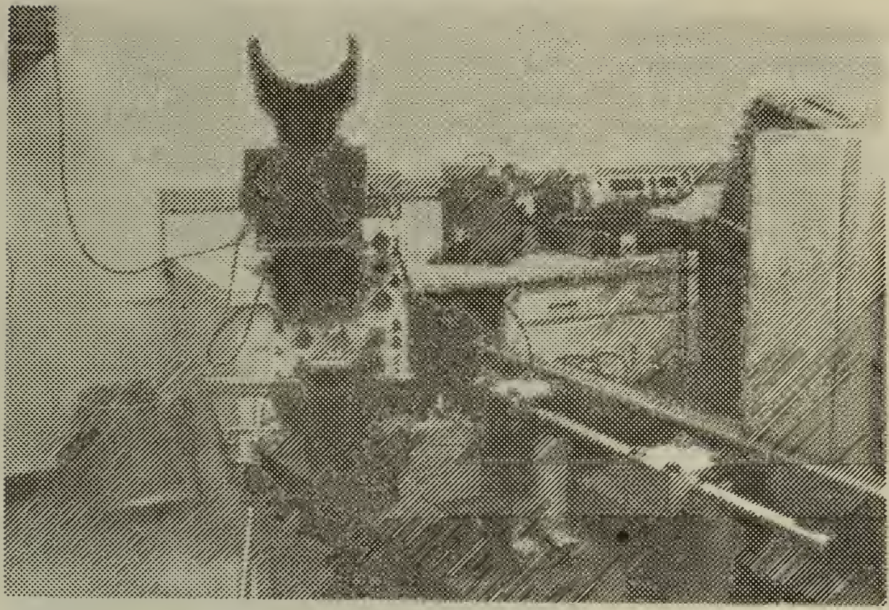
Pressure Transducer: Kistler Model 607A Quartz Pressure Transducer
Charge sensitivity 0.195 pCb/psi and range to 70,000 psi

Amplifier: Kistler Model 504 Universal Dial-Gain Charge Amplifier. Produces full-scale outputs from 1 psi per volt to 50,000 psi per volt for any charge input from .1 pCb per psi to 10 pCb per psi input sensitivity

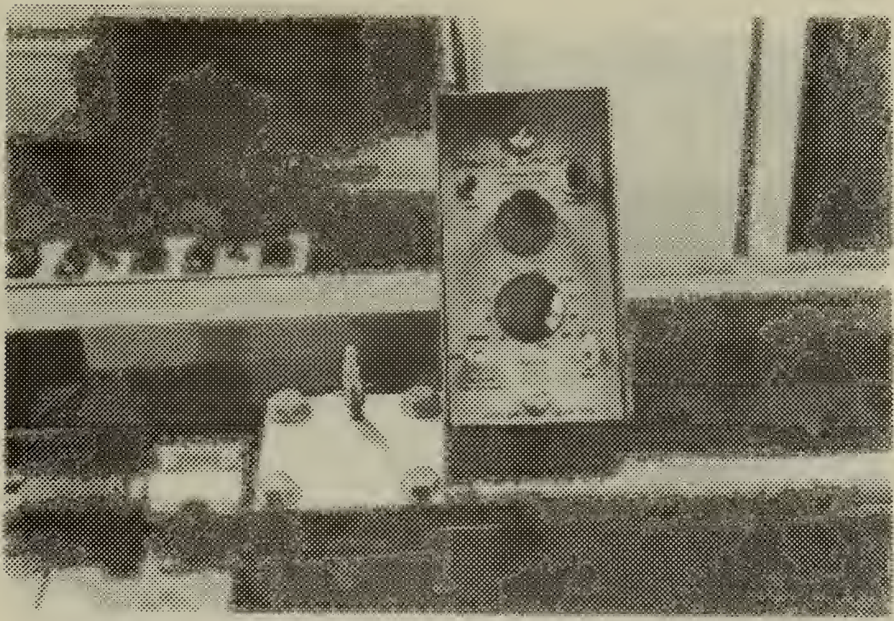
Oscilloscope: Tektronix Type 515A Oscilloscope mounted with Polaroid scope camera

APPENDIX B

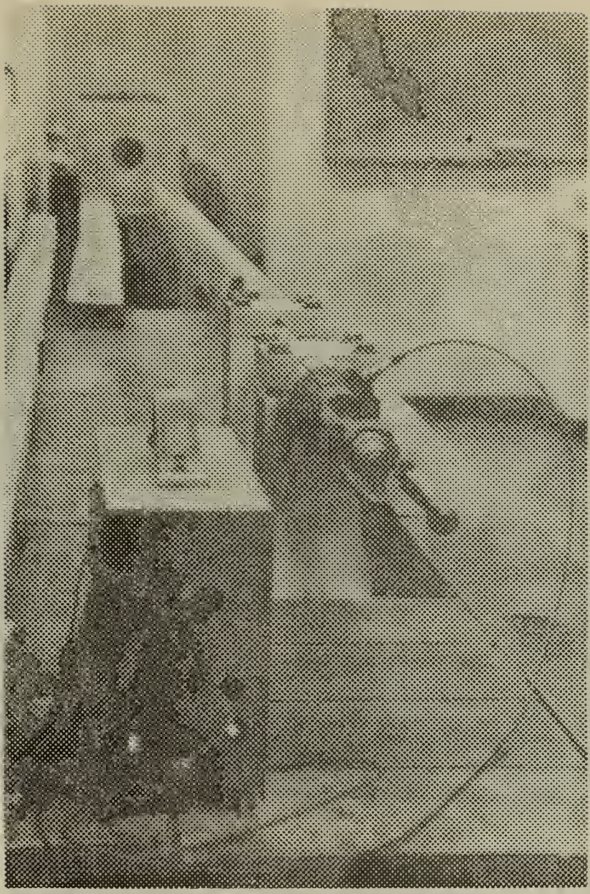
Photographs of Equipment Set-up



Oscilloscope and camera, amplifier, rifle on mounting

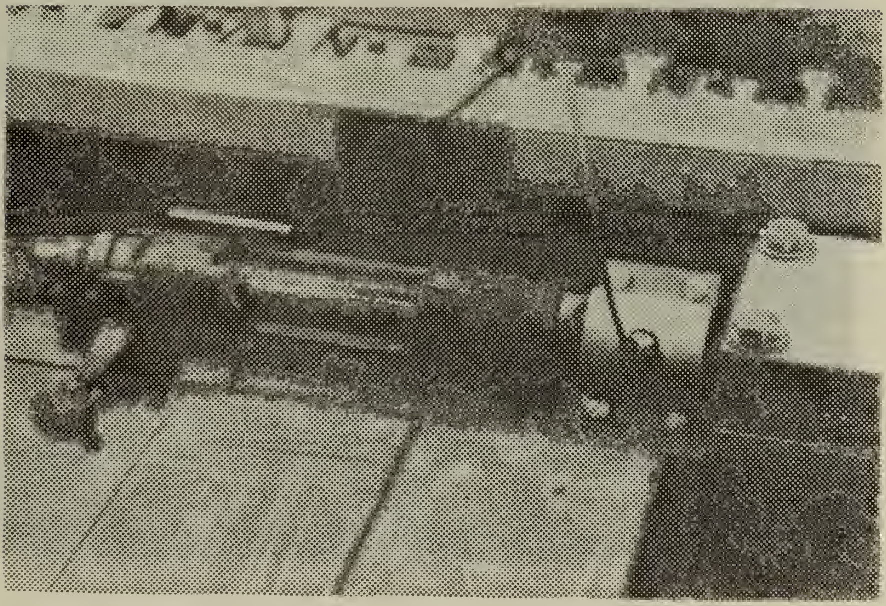


Transducer mounting collar, transducer, amplifier

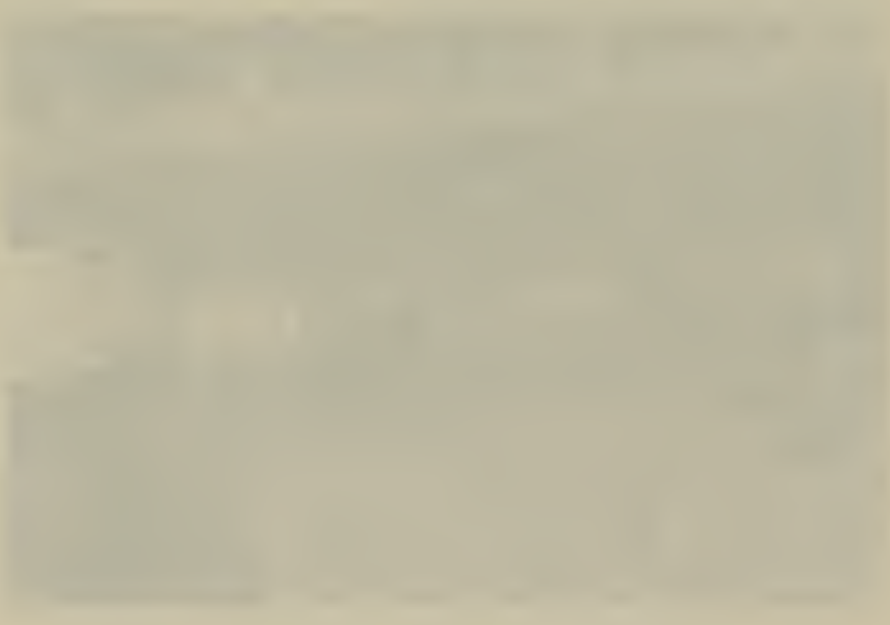


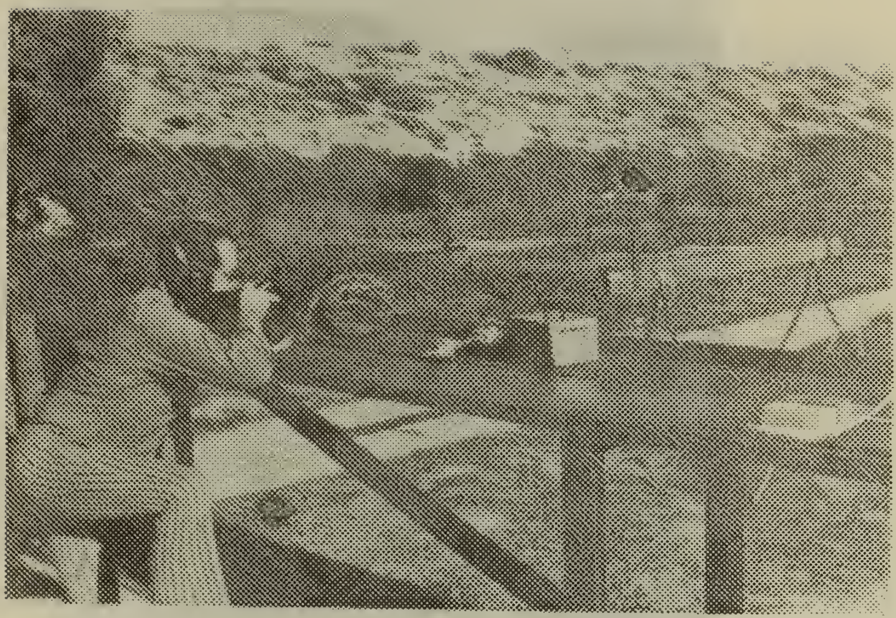
Mounted transducer hooked to amplifier.

Bullet trap with splash shield located 20 feet from the muzzle.

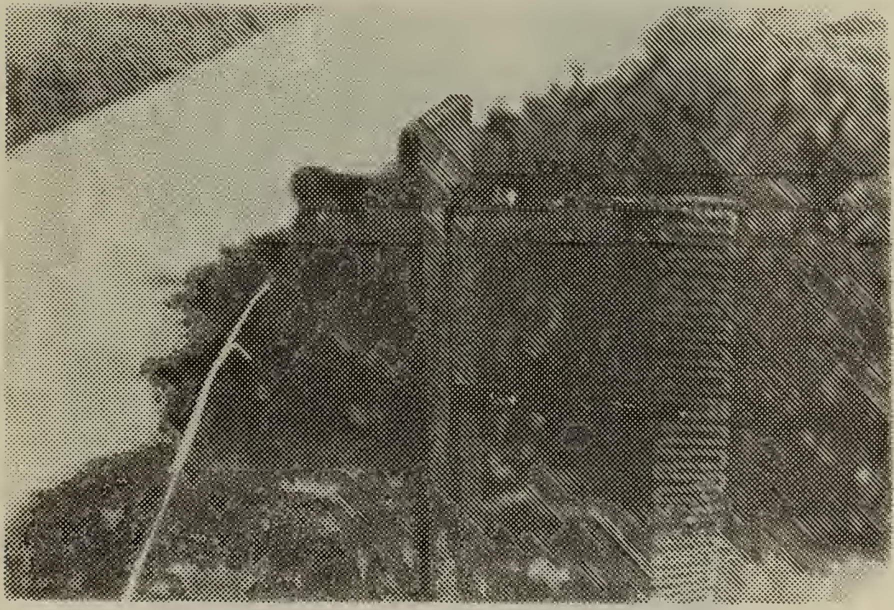


Transducer mounted in chamber.

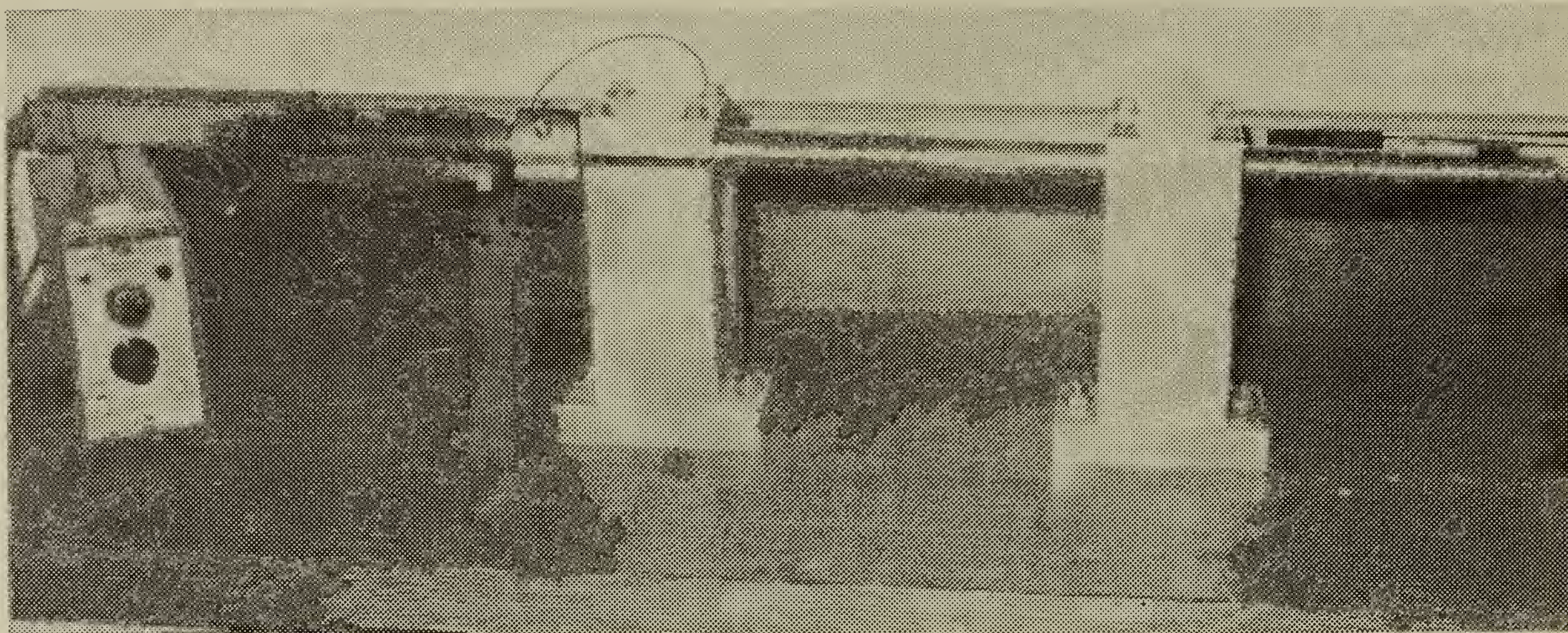




Firing conducted at outdoor range. Chronograph (on bench) hooked up to screens located 5 feet apart.



Single screen hook-up. Screen consisted of 35mm film with continuous metallic paint pattern inside.



Rifle mounted and secured on bench inside laboratory.

```
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      D=5.0
      F=100000.0
      S=1.0
      N=5
      DO 70 M=1,20
      WRITE (6,1000) N
      DO 80 J=1,999
      V=D*F/S
      WRITE (6,2000) V,S
      S=S+1.0
   80 CONTINUE
      D=D+1.0
   70 CONTINUE
      STOP
 1000 FORMAT ('0','FREQUENCY RANGE 100,000 HZ',//,' ',
     1'SCREEN SPACING',I2,'FOOT',//,' ','VELOCITY FT/S',T40,
     2'SCREEN READOUT')
 2000 FORMAT (' ',F12.3,T40,F12.0)
      END
$GO
//
```

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ABSTRACT

The effect of varying the point of ignition of the powder charge within a cartridge case was investigated with respect to both pressure and velocity. By installing a small tube in the base of the cartridge case it was possible to transfer the primer flash to the forward part of the case. Ignition of the powder charge at the top instead of the base gave lower chamber pressures by as much as 6,300 psi and increased muzzle velocity by 35 ft/s. When additional powder was added to obtain the same chamber pressure as a conventionally primed cartridge, muzzle velocities increased by 50 ft/s. Where the pressure was brought up past the original level, but kept within normally accepted limits for the 7.62mm NATO round, velocities increased by 100 ft/s over the original load. In order to shape the pressure curve, different loading schemes were tested. Various amounts of powders and powders of different burning rates were layered within the same case, the slowest burning powder being ignited first. Lower pressures and flatter pressure peaks were realized from these configurations. The chamber pressure was reduced by 6,000 psi and the muzzle velocity increased by 100 ft/s.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
small-arms						
forward priming						
cartridge case						
powder charges						
chamber pressure						
ammunition						
ordnance						

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Thesis
C9258 Culver
c.1 Velocity and pressure effects on projectiles due to vaiation of ignition parameters.